

A Dynamical Network Fault Setting approach for Joint Power Grid Simulation

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Abstract— In this paper, a dynamical network fault setting interface (DNFSI) for a joint simulation platform integrated by DIgSILENT and QualNet, where the data exchanging between QualNet and DIgSILENT is achieved by a power grid and communication co-simulation interface (PCCI), is proposed for the influence analysis of communication network fault on power grid. Together with the proposed DNFSI, the link or node fault of communication network can be dynamically configured via a graphical user interface (GUI) during the simulation. When the configuration messages of node or link fault setting are received from the GUI, these messages will be parsed and corresponding events will be pushed into the event queue of the network simulation of QualNet to model corresponding faults in the communication network of power grid. Experiment results prove the efficiency of the proposed DNFSI for the influence analysis of communication network fault on power grid.

Keywords— Dynamical fault setting, Power Grid, Co-simulation, Interface, DIgSILENT, QualNet

I. INTRODUCTION

Recently, with the increased interdependence of power system and its communication network, the influence evaluation of the communication network on the power grid becomes essential and simulations with only consideration of power grid cannot satisfy the requirement of testing and evaluating the power system with dynamic characteristics [1]-[2]. Thus, the co-simulation architecture has been widely considered by the academic and industrial researchers for improving the reliability and security of the power system attracts more and more attention [3-4] [5-8].

In [5], a collaborative simulation setup that aims to represent a better behaviour of smart grids was investigated and InSystemLab was considered as the middleware to combine various off-the-shelf computer simulators, e.g., EMTP-RV(Electromagnetic Transient Restructured Version), HYPERSIM(a fully digital real-time simulator), Simulink and OPNET. Based on the functional mock-up interface (FMI), a co-simulation approach that uses ns-3 for data exchanging with message-based model to achieve smart grid ICT (information and communication technology) assessments [6].

In addition, based on the RT-Lab and the OPNET, a co-simulation platform together with a synchronization method was designed to simulate man in the mid (MITM) attack, e.g., data interception and data modification, for the influence analysis of communication network problem on power grid system [7].

A federated simulation toolkit (FSKIT) that coupled continuous time and discrete event simulations (DES) to perform the co-simulation of GridDyn(a power transmission grid simulator) and NS-3 was introduced in [8] for the performance evaluation of power grid system. However, none of above works considers the dynamical fault setting method for the communication network of power grid system and the influence of dynamical fault of communication network on power grid is unavailable to be analysed in a dynamical manner. Even though a real time user interactive approach, by which the parameters of network model were able to be dynamically reconfigured during the simulation process, was introduced for the network model evaluation [9]. However the approach for network fault setting for the joint power grid simulation is not further considered.

In this paper, a dynamical network fault setting approach is proposed for joint power grid simulation platform integrated of QualNet, DIgSILENT, and GUI. Owing to the proposed DNFSI, the data interaction in joint power grid simulation is achieved and communication network failures can be dynamically configured through a GUI during the simulation process, which provide the potential to dynamically analyse the impact of communication network on power grid. When QualNet receives packets, e.g., data packets or configuration packets, from DIgSILENT or GUI, each packet will be parsed based on its time stamp, and then, a corresponding discrete event will be generated and pushed into the event queue of QualNet to model the corresponding network faults based on its time stamp.

The remainder of the paper is organized as follows. In Section II, the proposed DNFSI as well as PCCI for dynamical link fault setting and node fault setting in a joint power grid simulation platform integrated by DIgSILENT and QualNet are described in detail. Intensive experiments are

performed to evaluate the proposed interfaces in Section III. Finally, Conclusions are drawn in Section IV.

II. PROPOSED DNFSI AND PCCI FOR JOINT POWER GRID SIMULATION SYSTEM

A. Architecture of joint power grid simulation system

The proposed joint power grid simulation platform is shown in the Fig. 1. A GUI for dynamical fault setting is connected with QualNet which is utilized to simulate the communication network of power grid system. DNFSI enable users to set node or link faults in the network model of QualNet. Meanwhile, DIgSILENT which include power equipment models library and analysis tools for power system, is connected to the QualNet via proposed PCCI, which enable the DIgSILENT to simulate the effects of communication networks on power grids with the aid of QualNet. Together with the joint power grid simulation platform the impact of communication network on power grid can be analysed dynamically.

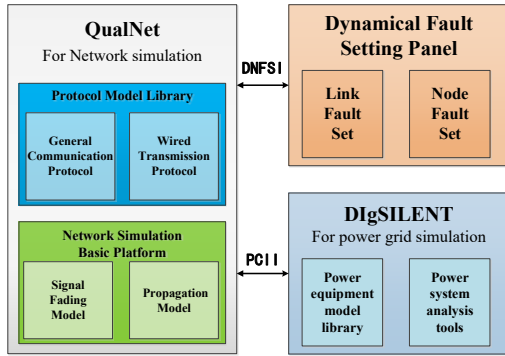


Figure 1. Architecture of joint power grid simulation system

B. Function flow chart and frame structure of PCCI

The function flow chart of proposed PCCI is shown in Fig. 2 and corresponding key functions are described as following:

Initialize Handler(): is used to keep on listening the port of socket to receive packets sent by the DIgSILENT.

Handle Interaction(): Each packet sent by the power grid simulator consist of several sub-packets and each sub-packet corresponds to an discrete event. Whenever the interface receives packets, three parameters, i.e., Count, To_Power_Simulator, and Unionsimdata, will be saved at the receiver buffer. Count indicates the amount of sub-packets sent from DIgSILENT to QualNet. To_Power_Simulator indicates the packets are to be sent from QualNet to DIgSILENT. UnionSimData includes the communication data packets sent from DIgSILENT to QualNet and its specific structure is given in Fig. 3. Finally, each packet after function of Handle Interaction() will be transformed to a corresponding discrete event for QualNet.

Process Event(): When a discrete event occurs, this function will be utilized by the QualNet, and the corresponding function of processing message will be called for the node where the event happens on.

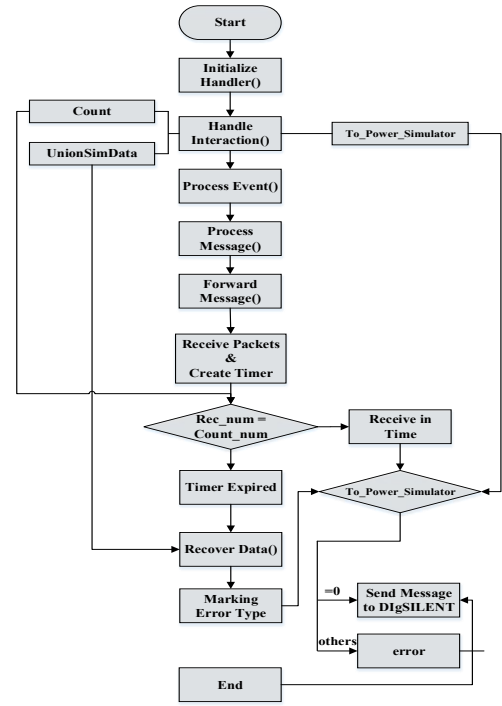


Figure 2. The function flow chart of PCCI

4 bytes	4 bytes	4 bytes	4 bytes	4 bytes	8 bytes	24 bytes
Realtime	Sim_time	Src_id	Dst_id	Err_type	Dst_id	Power_data[]
Time stamp		Communication SimData			Power grid Data	

Figure 3. Specific structure of UnionSimData

Process Message(): generate the corresponding message, i.e., grid message as shown in Fig. 4, sent to the application layer of specific node in QualNet. Compared with structure of UnionSimData in Fig. 3, additional parameters are added, i.e., Count, Index, To_Power_Simulator, and Txtime. Count indicates the number of packets sent to QualNet. Index represents the sequence number of packets sending to application layer. To_Power_Simulator specifies that packets will to be sent from QualNet to DIgSILENT. Txtime illustrates the sending time.

52 bytes	4 bytes	4 bytes	1 bytes	8 bytes
UnionSimData	Count	Index	To_Power_Simulator	Txtime

Figure 4. Specific structure of grid message

Forward Message(): is called for sending message generated by Process Message() to the Application layer of specific node in QualNet via UDP.

Receive Packets(): If all packets are correctly received, these packets will be packed and sent to the DIgSILENT. Otherwise, the function of Recover Data(), which compares the received packets with Unionsimdata saved in receiving buffer, checks which packets are missing. If a missing packet is found, the Err_type in the Unionsimdata of grid message will be set as 5 and send to the DIgSILENT.

C. Function flow chart and frame structure of DNFSI

The function flow chart of proposed DNFSI for network fault configuration is shown in Fig. 5 and corresponding key functions as well as message types are described as following:

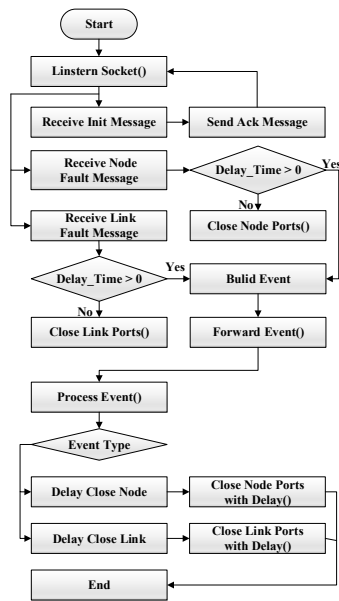


Figure 5. The function flow chart of DNFSI

Listen_Socket(): is used to keep on listening the port of socket to receive messages sending by GUI, including initialization message, node fault message, and link fault message.

Init message(): represents a message sent by GUI to ensure the connection between QualNet and GUI. Meanwhile, an Ack message will also be fed back to figure out the beginning of fault configuration by this function.

Node fault message(): indicate a node fault in a network simulation model is to be configured. The specific structure of node fault setting message is given in Fig. 6. IP_Addr refers to the IP address of server for QualNet. Port indicates the port of server for QualNet that messages will be sent to. If $\text{Delay_time} \leq 0$, all ports of the target node will be closed, which implies that QualNet received node fault setting message, otherwise an event will be generated based on the specified delay according to Delay_time and be pushed into event queue of QualNet on time.

8 bytes	4 bytes	4 bytes	4 bytes	8 bytes
Ip_Addr	Port	Type	NodeId	Delay_Time

Figure 6. Specific structure of node fault setting message

Link fault message(): indicate a link fault in a network simulation model is to be configured. The specific structure of link fault message is shown in Fig. 7. As same as node fault message, link fault message have parameters including Ip_addr, Port, Type, and Delay_time. In addition, the NodeId1 and the NodeId2 indicates where the link is set as fault link.

8 bytes	4 bytes	4 bytes	4 bytes	4 bytes	8 bytes
Ip_Addr	Port	Type	NodeId1	NodeId2	Delay_Time

Figure 7. Specific structure of link fault setting message

Process Event(): when a discrete event occurs, Process Event() first check the event type. If the type is Delay_Close_Node which corresponds to the node fault setting event, the function Close_Node_Ports() will be called and all the ports of a specific node will be closed. Otherwise, the function of Close_Link_Ports() will be called to close ports of the specific link to model the link fault between NodeId1 and NodeId2 in the simulated network model.

III. EXPERIMENTS AND RESULTS

The following experiments are based on QualNet 5.1 and DlgSILENT with proposed interface and GUI. The parameters of simulation servers are listed in Table 1. The IEEE 39 Bus System is selected as testing scenario as shown in Fig. 8. The corresponding topologies simulated in both DlgSILENT and QualNet are respectively described in Fig. 9(a) and Fig. 9(b). In experiments as shown in Fig. 10, a CBR (Constant Bit Rate) application of voltage correction parameter is set from node 25 to node 22, where the packets are transmitted through the path of nodes after initial route discovery, i.e., 25-24-27-28-22, and the node 25 is regarded as the dispatch center. Meanwhile, another CBR application is set between node 1 and node 10 to provide the background traffic of the system, where background traffic are transmitted via a path of 25-26-14-13-5-4-2-1.

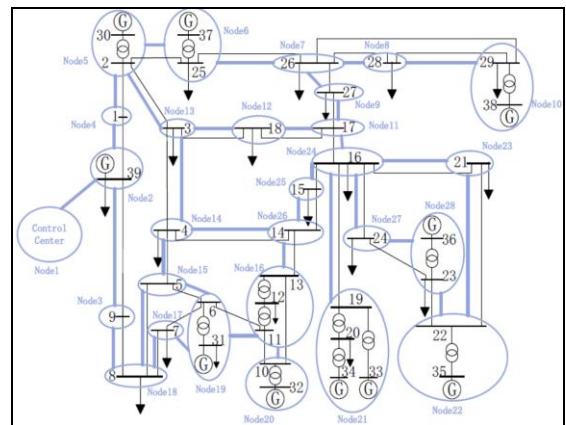
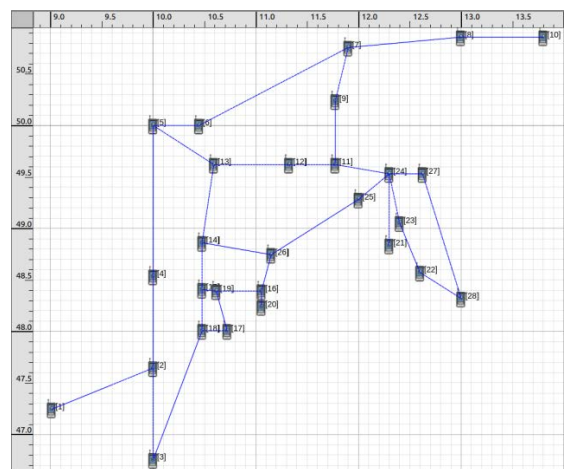


Figure 8. Topology for IEEE 39 Bus System



(a) Simulated topologies in QualNet

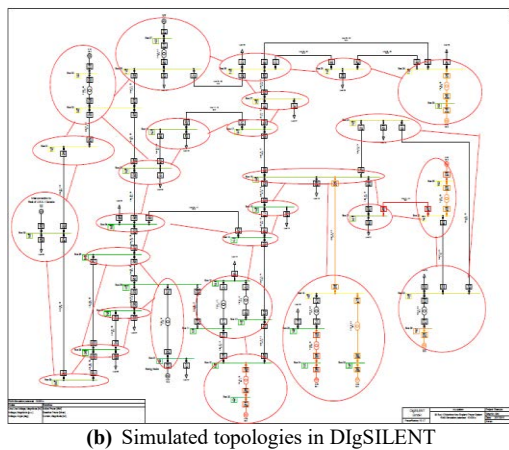


Figure 9. Simulated topologies in QualNet and DigSILENT

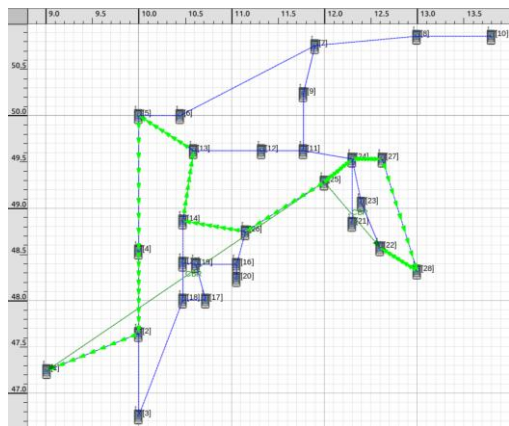


Figure 10. CBR application and its transmission path in experiments

TABLE 1. PARAMETERS OF SIMULATION SERVERS

	QualNet	DigSILENT	Setting Panel
Operation System	Ubuntu 12.04	Win10 professional	Win10 professional
CPU	Intel core i7 4700MQ	Intel core i7 Q720	Intel core i7 Q720
RAM	3.5GiB	4.0GiB	4.0GiB

A. Test of node fault setting

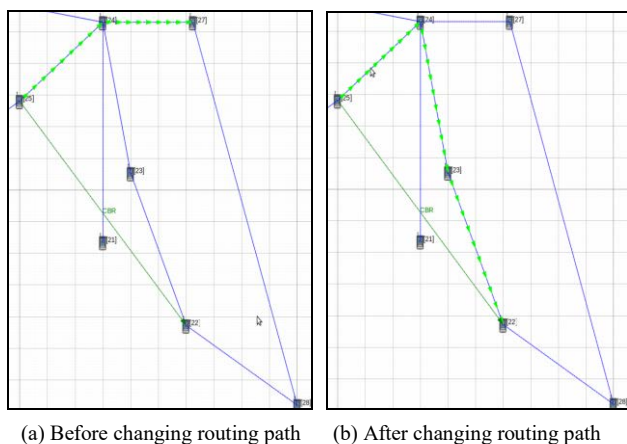


Figure 11. Transmission path changing with fault configuration at node 28

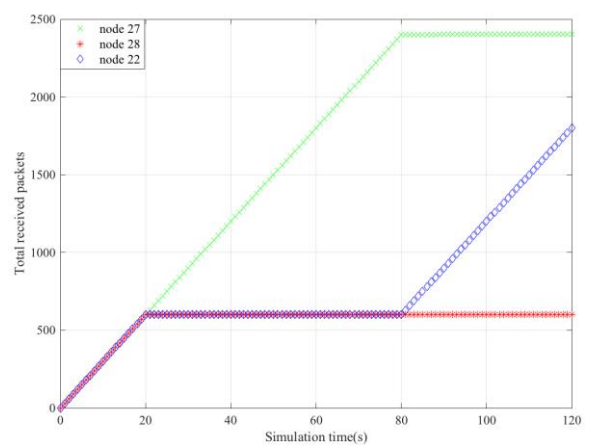


Figure 12. Total packets respectively received by node 27, 28 and 22 with node fault configuration at node 28

In the experiment, routing protocol of Bellmanford is utilized in the network model for IEEE 39 Bus System. At the simulation time of 20s, the node 28 will be set as fault node through GUI. Thus, the routing path of CBR from node 25 to node 22 is changed to from 25-24-27-28-22 in Fig. 11(a) to 25-24-23-22 in Fig. 11(b). Since the routing path of 25-24-27-28-22 for CBR application is unavailable anymore, the routing table for the IEEE 39 Bus System will be updated according to the Bellmanford protocol, which results into a flat trend of total received packets at nodes 22 and 28 during the simulation time from 20s to 78s as shown in Fig. 12. However, the node 27 as a reception node still can correct receive the packets from node 24, thus a linear increased trend of total received packets can be observed. At the simulation time around 78s, the routing table updating is established for each node and a new routing path of 25-24-23-22 is selected. Thus, a linear increasing trend of total received packets at node 22 and a flat trend of total received packets at node 27 as well as node 28 can be observed respectively.

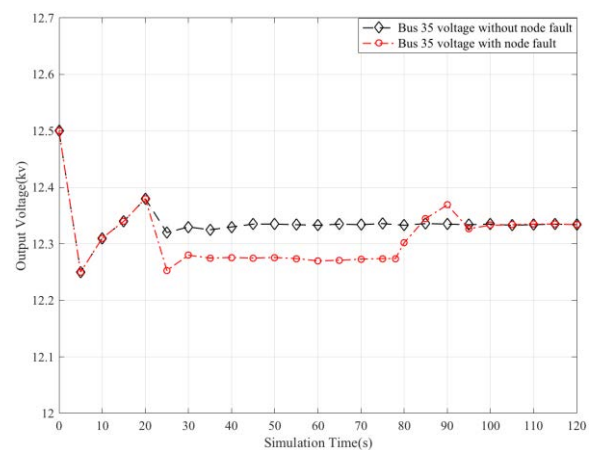


Figure 13. Voltage of Bus 35 with node fault configuration at node 22

Furthermore, the voltage of Bus 35 in DigSILENT, which corresponds to node 22 in QualNet, is given in Fig. 13. Due to the fault configuration on node 28 at 20s, a significant fluctuation of output voltage is observed at Bus 35, since the

voltage correction parameters from dispatch center are lost. However, at simulation time of 78s, owing to the establishment of new routing table at all the nodes, the voltage correction parameters from dispatch center can be received by the Bus 35 and a flat output voltage can be achieved. Thus, together with proposed DNFSI, the node fault of network for power grid simulation system can be dynamically and efficiently configured.

B. Interface delay test

In order to evaluate the access delay of proposed DNFSI and DCCI, intensive experiments have been conducted for the cases with background traffic and those without background traffic as shown in Fig.14. The total access delay of DNFSI or DCCI, D_{total} , can be presented as $D_{total}=D1+D2+D3+D4$. D1 is the time consumption for calling the receiving function. D2 denotes the time consumption for packet parsing and rebuilding. D3 indicates the time consumption for event processing and D4 denotes the time consumption for information feedback. In addition, since more packets will be transformed and processed by the PCCI compared to those by DNFSI, a larger averaged access delay of PCCI can be observed. In addition, with more background traffic, a higher access delay will be achieved. However, compared with the transmission delay of data traffic, the access delay of proposed interfaces are acceptable.

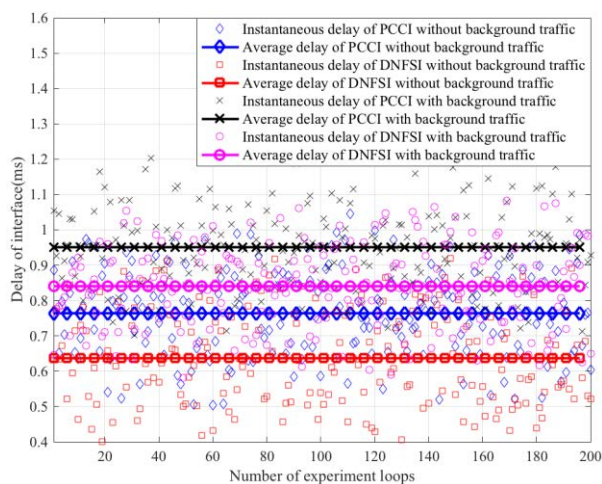


Figure 14. Access delay of proposed DCCI and DNFSI

IV. CONCLUSIONS

In this paper, the DNFSI and the PCCI are investigated for the joint simulation platform integrated by DiGSILENT and QualNet, for the influence analysis of communication network fault on power grid. Together with the proposed DNFSI, link fault or node fault of communication network can be dynamically configured via a graphical user interface (GUI) during the simulation. When the configuration messages of link fault setting are received, the corresponding discrete events will be pushed into the event queue of the network simulation to model corresponding faults in the communication network of power grid. Experiment results prove the validity efficiency of proposed interfaces.

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