CO-SIMULATION ARCHITECTURE FOR CENTRALISED DIRECT LOAD CONTROL IN SMART GRID

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ABSTRACT

The Co-Simulation in the paper aims to simulate a smart grid with its two components. The approach of a common co-simulation also provides new insights for both affected domains. In the domain of communication networks, new insights about the demands of such smart grid communication can be gathered. This concerns not only the data volume and timing questions, but also reliability issues. To investigate the behaviour of the combined electrical grid and the communication network, PSS SINCAL and OPNET simulators are combined and a direct load control algorithm is implemented and tested on German distribution network.

INTRODUCTION

As existing power simulators are not capable to simulate network communication protocols and traffic patterns, their application are limited to simulate smart grid. Due to aforementioned reason, designing a new simulator can be expensive [1]. However, a solution can be achieved by integrating dedicated tools in one framework. Several architectures such as EPOCHS [2], GECO [3], INSPIRE [4] have been proposed in last years. And the requirements and synchronization techniques in co-simulation can be found in [1, 5]. Regarding the application areas, a co-simulation mainly is used for time critical study (dynamic simulation) or for steady-state condition such as Demand Response (DR) or Optimization [1, 6].

In Smart Grid projects, DR is mainly divided into two categories: price based and incentive based program. [7].Direct load control (DLC) belongs to incentive based programs. And, the goal is to reduce the stresses on a grid with shedding some part of the loads during peak hours by system operator remotely [7]. In this study, it is assumed that consumption behaviour of the costumers during peak hours can be changed by system operator remotely. Besides, it is assumed that day-ahead system condition is forecasted accurately.

ARCHITECTURE

In Figure 1, an overview of the co-simulation architecture is shown. The whole setup is divided in the two domains of energy and communication grid that meet in a common simulation management tool. The simulation management tool acts as the coordinator of the co-simulation.

One of the most important functions of the simulation management tool is the time synchronization of both simulation tools. Furthermore, it coordinates the information exchange between both simulation tools and provides a mapping of both simulation models.

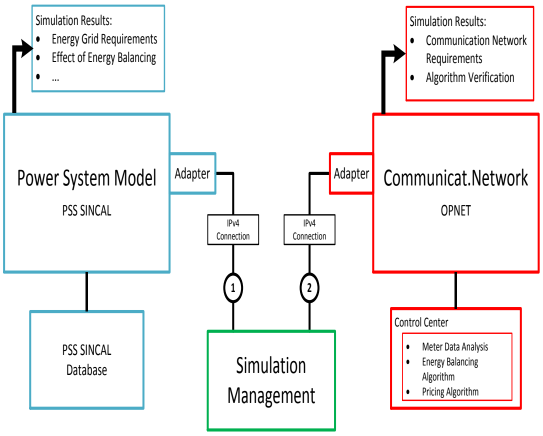

Figure-1: The Architecture.

The simulation management tool connects both simulation tools with a TCP/IPv4 connection using XML-messages.On the left side of Figure 1, the energy grid simulation domain is shown. This simulation is based on PSS SINCAL, a tool for the simulation of energy networks. To control the simulation from an external application, an adapter is needed and it has been implemented with COM interface. Regarding the communication network it is shown on the right side of Figure 1. The well-established simulation tool OPNET Modeler (recently also known as Riverbed Modeler) is used to simulate this domain. Also the grid control algorithms are implemented here. One way to interconnect the OPNET Modeler with real network equipment during simulation is the external system approach. The following components: External System Definition (ESD) model and External System (Esys) module have been implemented for the adapter on communication side.

The network model in the architecture is shown in Figure 2.In order to explain the network model in OPNET, we should break it down to three different abstraction levels such as network, node and state. Multiple nodes are connected to each other to form the network, where each node is controlled by a state diagram.

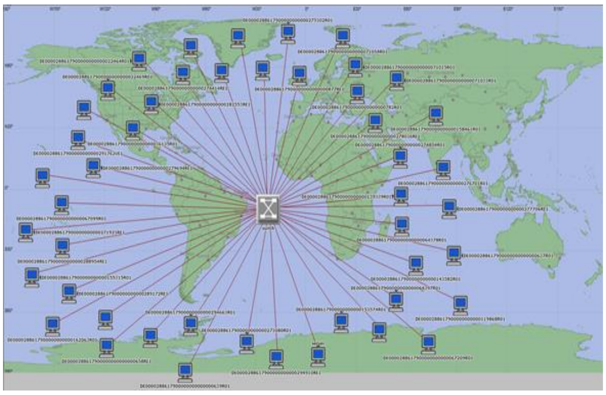

Figure-2: Network Model in OPNET.

In Figure 3, process and node model is shown. The process model describes the interaction and transitions with external program .There are 5 different states that control behaviour of a node which is INIT, IDLE, STRM, ESYS and ESYS_EVENTS. ESYS state is triggered by the external program, changing the interface value where events are scheduled for further interrupts that will result in a state change. ESYS_EVENTS is the state that is activated via the Co-Simulation program where a packet with information of simulation is generated and sent.

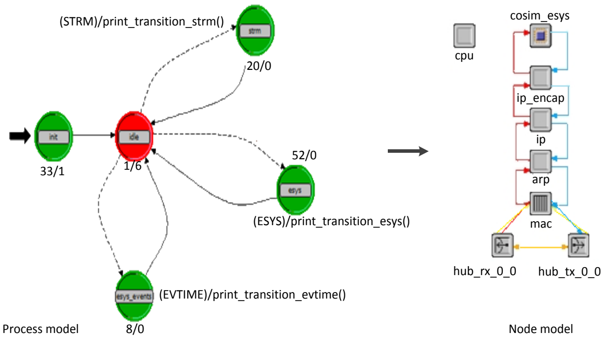

Figure-3: Process and Node Model in OPNET.

The nodes are run under "Ethernet_ip_station_adv_esys" model under OPNET which represents a simple traffic source running over IP stack. The reason for the use of this model is that Ethernet and IP connection are commonly and widely used in real world communication network. In order to support this model each of the nodes are connected via 100 BaseT Ethernet links. Each node requires a fixed amount of time to route each packet, as determined by the "IP Forwarding Rate". Packets are routed on a first come first serve basis and may encounter queuing at the ports depending on the transmission rates of the output interface. Regarding the node model, ip_cap encapsulates the packets into IP datagram, ip is in charge of traffic control process and macis responsible of quality of servise (QoS) and scheduling. In addition to this, hub_rx_oo and hub_tx_oo act as receiver and transmitter respectively.

As relaying and forwarding will require more complicated node model, each of the nodes are connected in a star topology to a switch where the nodes would require only receive or transmit functionality. The exception is the one node that acts as a server to obtain the full picture of the network. The address of the server will be the host address of the network, and all of the other nodes will set this address as the destination address so it will act like a sink for the network.

EVENT FLOW IN THE ARCHITECTURE

The simulation management tool is the core of the co-simulation setup. It connects both simulation tools and ensures time synchronization. Moreover, it also coordinates the information exchange between both simulation tools. The simulation management tool is implemented in C++ using the Visual-C++-Compiler and the Windows libraries. To provide a flexible way to connect both simulation tools, the simulation management employs XML-messages over TCP/IPv4 to transfer information between the entities.

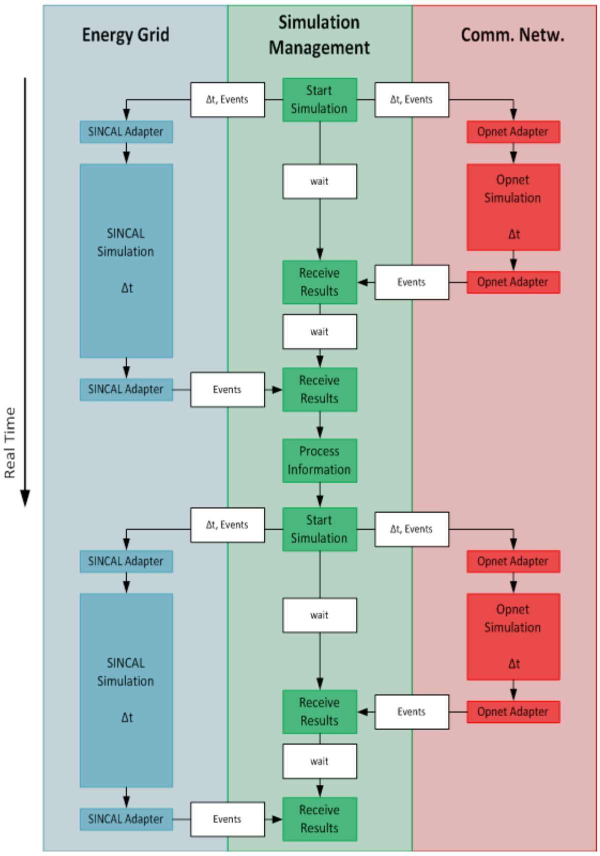

Figure-4: Event flow in Co-simulation.

This way all three applications, the simulation management tool, the energy grid simulation and the communication network simulation, can be placed even on physically different devices as well as on one single host.

This also enables the split of the development activities into different independent domains. An example for the event flow in the co-simulation is given in Figure 4. The simulation management tool always starts the next iteration, giving the Δt, the time the simulation shall advance, and the events that will happen during the next or a future iteration. This information is to be processed by both simulation adapters and is considered during the next simulation iteration. While both simulation tools simulate the next iteration step, the simulation management tool waits for both simulations to finish. After each simulation finishes, the results of the simulation run are collected by the simulation adapters and sent back to the simulation management tool in an XML message. There the information from both simulation tools is processed and the next simulation iteration is prepared and started.

CONTROL METHOD

The proposed control method is shown in Figure 5. Once the measurement is available, the algorithm detects if there is a violation. Then it detects critical points in the grid and finds a list of the costumers that are in this area. The nodes are differentiated according to their costumers ID and a customer can be either controllable or non-controllable. In addition to this, active power of PV system is not shed. When list of the controllable costumers are found, a load reduction request is sent to them in order to reduce consumption.

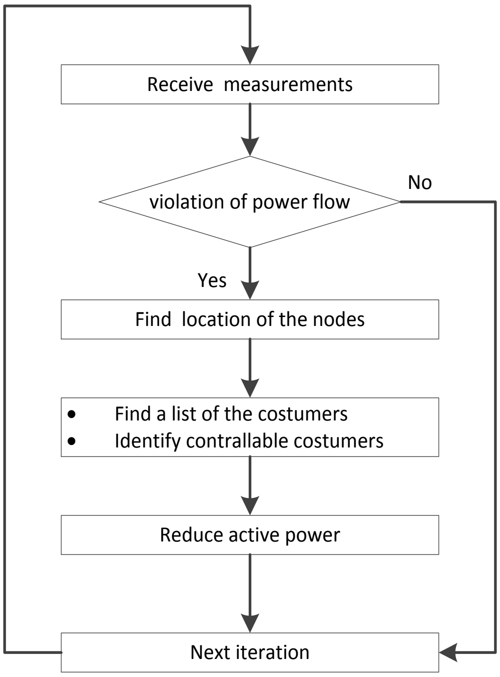

Figure-5: Control Method.

In our model we assume the control action can be applied remotely whenever there is a problem in the grid. And reduction step can be varied. However, in real situation a costumer has right either to accept or reject a controlling while taking maximum number of a load reduction request into account.

CASE STUDY

In order to test the proposed architecture, the load profile calculation so called quasy-static time-series analysis is used as a calculation method in PSS SINCAL and simulated for one day. The architecture has been tested on Augsburg network and the grid has been modelled in PSS SINCAL which is shown in Figure 6.

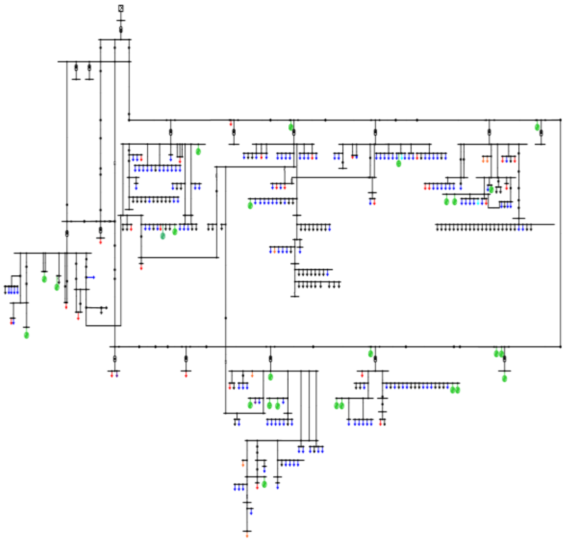

Figure-6: The Grid Model.

Historical consumption and generation profiles have been assigned to the loads and PV system respectively. All the network data such as consumption profiles, photovoltaic generation profiles has been provided by Stadtwerke Augsburg .Approximately number of fifty costumers has been selected to participate in DR. As there is no any overloading in original network, some profiles are modified to validate the test method. The time step in simulation is chosen with 5min interval. Which means the hole day is simulated with Δt=300 sec. Since there are many loads with different consumption profiles in the grid, the result is shown only for one customer.

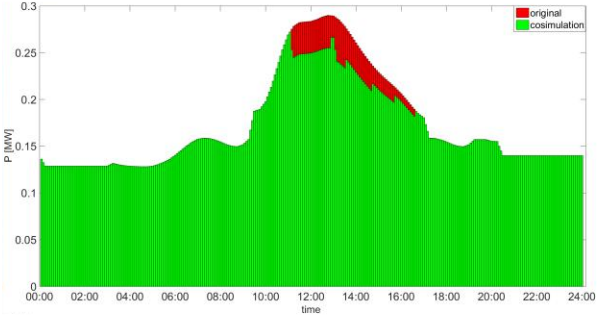

Figure-7: Consumption profile of costumer No: 1.

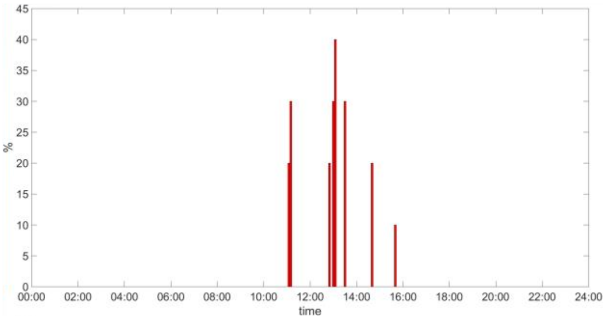

Figure-8: Control command of the customer No: 1.

The difference between original and co-simulation is given for customer no:1 in Figure 7. During peak hours when the gird is overloaded the costumer receives a load reduction request in order to shed some part of the loads. It can be clearly seen that the algorithm can effectively eliminate the overloading by applying peak shaving. The control command of costumer 1 which is shown in Figure 8 starts nearly at 11h and the maximum reduction reaches to 40% during the day. Regarding the network traffic, it was analysed at different communication nodes during the simulation run and the situation at the server side is shown in Figure 9. The incoming traffic is very equally distributed over time and it shows little variation between 0,00 and 0,06 packets/s with just some peaks up to 0,12 packets/s.

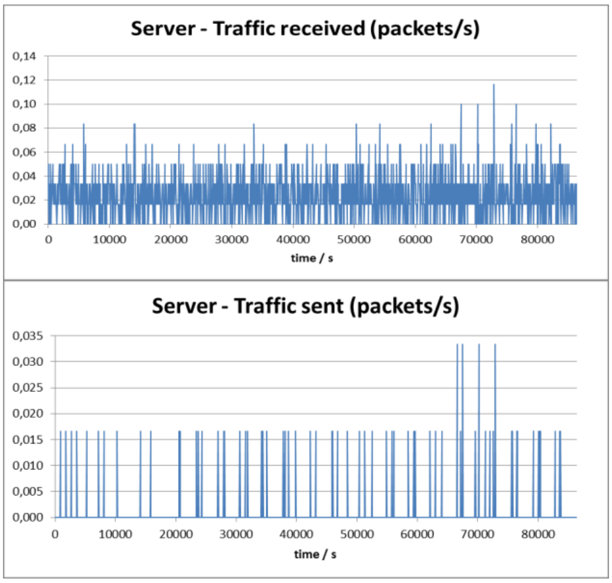

Figure-9: Received and Sent traffic on Server side

CONCLUSION AND FUTURE WORK

In this paper power system simulator (PSS SINCAL) and communication network simulator (OPNET) is combined to form the co-simulation architecture. The proposed architecture was tested on distribution network model with centralised direct load control. The effectiveness of the control method was validated by quasi-static time series simulation. The future works will focus on comparison between real field test and co-simulation. Additionally, more advanced scenarios will be simulated such as considering a number of maximum control commands per costumer and dynamic price.

ACKNOLEDGMENT

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REFERENCES

[1] K.Mets, L.Ojeal, C.Develder, 2014, "Combining Power and Communication Network Simulation for Cost-Effective SmartGridAnalysis", *Communications Surveys & Tutorials, IEEE.* vol. 16, pp.1771 - 1796.

[2] K.M Hopkinson, K.P Birman, R Giovanini,D.V Coury,X.Wang, J.S Thorp, 2003, " EPOCHS: integrated commercial off-the-shelf software for agent based simulation ", *Proceedings Simulation Conference, IEEE.* vol. 2, pp.1158 - 1166.

[3] H.Lin, S.Veda, S,Shukla, L.Mili, J.Thorp, 2012, "GECO: Global Event-Driven Co-Simulation Framework for Interconnected Power System and Communication Network ", *Smart Grid, IEEE Transactions on.* vol. 3, pp.1446-1456.

[4] H.Georg, S.C.Muller, N.Dorsch, C.Rehtanz, C.Wietfeld, "INSPIRE: Integrated co-simulation of power and ICT systems for real-time evaluation ", *Smart Grid Communications*, IEEE International Conference on, pp.576 - 581.

[5] W.Li, M.Ferdowsi, M.Stevic and A.Monti, 2014, "Co-Simulation for Smart Grid Communications ", *Industrial Informatics, IEEE Transactions on*, vol. 10, pp.2374 – 2384.

[6] M.Stifter, R.Schwalbe, F.Andren, T.Strasser, 2013, "Steady-state co-simulation with PowerFactory ", *Modelling and Simulation of Cyber-Physical Energy Systems, Workshop on, IEEE*, pp.1- 6.

[7] Q.Zhang, J.Li, 2012, "Demand response in electricity markets: A review", *IEE European Energy market conference*, pp.1-8