CO-SIMULATION OF ICT TECHNOLOGIES FOR SMART DISTRIBUTION NETWORKS

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ABSTRACT

In future smart distribution networks the expected bidirectional exchange of large amount of data will create a keen interdependence between electric system and ICT system. In this perspective co-simulation tools are essential to simulate the power distribution system and the ICT system behaviour simultaneously, taking into account the relationship among the two systems.
In the paper different ICT solutions for Smart Grids are compared considering their performances in order to estimate their suitability for smart grid applications. Given the complexity of future Smart Grid and the need to include in the studies also the LV distribution networks, the main novelty of the co-simulation tool presented is the ability to simulate different transmission media simultaneously.

INTRODUCTION

The transition towards smart distribution networks (SDNs) involves an extensive use of information and communication technology (ICT) and innovative control systems in order to enable the active management of distributed energy resources (DERs) and expected growing number of electric vehicles.
In SDN context, therefore, ICT is not a simple auxiliary infrastructure of the electrical system, but a fundamental component for the effective operation of the entire power distribution system, in order to ensure reliable and real-time data collection from an enormous number of widely dispersed data sources and a responsive data transmission for power network control.
A variety of ICT technologies can be considered for SDN applications. They can be mainly classified into two categories: wireless technologies and wired technologies. Wireless technologies, like WiMAX, Wi-Fi, LTE, are finding a growing interest for applications in the electric utilities, because of their lower cost of installation if compared with wired technologies. On the other hand, wired technologies, such as optical communication, digital subscriber line (DSL) and power line communication (PLC) are also considered as candidates for smart grid implementation, since they guarantee high reliability and bandwidth.
In the paper different ICT solutions for Smart Grids are compared with a co-simulation platform. The bidirectional exchange of large amount of data creates a keen interdependence between electric system and ICT system. Co-simulation is therefore an essential method to simulate the power distribution system and the ICT system behaviour simultaneously, taking into account the relationship among the two systems. In the paper the co-simulation is performed by a specific software developed by the authors, which adopts a power system simulator (OpenDSS) and a ICT network simulator (ns-3), and is able to analyze smart grid environments and scenarios.
In the study case a MV/LV smart distribution network will be analysed, where a complex ICT network supports the communication infrastructure between the distribution management system (DMS) and the active resources of the Smart Grid. The MV network is supported by a long range communication technology, such as WiMAX, meanwhile the LV network is managed by Wi-Fi or PLC communication technologies. Different ICT topologies will be compared, and their performances will be analysed, in order to estimate their suitability for Smart Grid implementation.

SMART DISTRIBUTION NETWORKS

In SDN, ICT is not a simple add-on of the electrical system, but its availability and efficiency is essential to the operation of the entire power distribution system as support of network management. In fact, the inherent variability and unpredictability of the power generation from renewable sources, along with the expected growing number of electric vehicles with their storage capacity and their mobility [1], requires a continuous flow of information in order to verify the compliance with network constraints and optimize the energy flow.

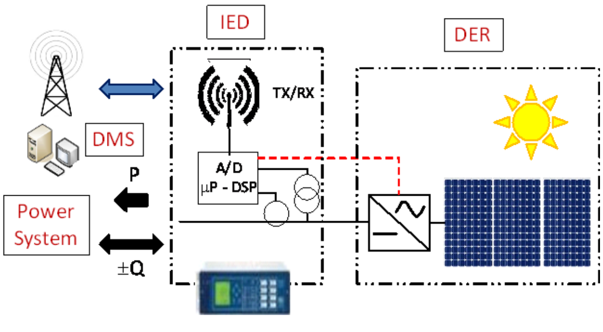

Figure 1. ICT and power system interaction in SDN

In an SDN a centralized/decentralized distribution energy management system (DMS/EMS) supervises the operation of the electric distribution network gathering measures of the main electric variables from intelligent electronic devices (IEDs) and, according to the control scheme, modifies the set point of DERs directly connected to MV distribution network or interact with the energy management of LV and/or Microgrids (Fig. 1)
Communication between a centralized DMS/EMS and DERs is dependent on the efficiency and reliability of the ICT infrastructure. In fact, the transmission of the control signal relies on many variables that define the ICT system, both in terms of technologies and conditions in which the signal transmission occurs, especially if it spreads through a wireless medium. Technologies such as wired networks (e.g. cable, PLC, Optic Fiber), or wireless networks (e.g. WiMAX, LTE, Wi-Fi) are characterized by distinctive critical issues, e.g. the level of noise in the transmission medium or, in the case of wireless media, by environmental and topography conditions of the site where the transmission occurs as well as meteorological conditions (e.g. rain, snow). Simulation tools are needed to ensure that ICT solutions are consistent with the reliability requirements of a SDN.

THE CO-SIMULATION TOOL

A new architecture for jointly simulate power systems and ICT systems has been developed as an improvement of the co-simulation tool presented in [2]. This co-simulation tool adopts Open Distribution System Simulator (OpenDSS) as power system simulator, whereas Network Simulator 3 (ns-3) is employed as discrete event simulator for the communication system. Both software products are free and open source. MATLAB® works as run time interface (RTI) between OpenDSS and ns-3. Fig. 2 shows schematically the architecture of the co-simulation tool.
The whole process of co-simulation is managed by MATLAB® under which the distribution/energy management system (EMS/DMS) is also implemented. Communication between MATLAB® and OpenDSS is made possible by a Component Object Model (COM) interface of OpenDSS, implemented on an in-process server DLL version of the program. Integration of ns-3 in the co-simulator is obtained through a SSH/SCP interface that allows Windows SO to communicate with a Linux virtual machine, where ns-3 is installed, as ns-3 is a software which runs on UNIX systems. The MATLAB® event-coordinator charges OpenDSS to perform power flows according to a specific time scale that is related to the time granularity imposed by the simulation.
The software ns-3 is one of the most used communication network simulator tools in the field of teaching and scientific research [3]. The high participation of the scientific community to the ongoing development of the software allows ns-3 to be a continuously updated tool, ensuring a constant alignment of the libraries to the latest standards of protocols and telecommunication technologies. Several communication technologies can be simulated with ns-3, e.g. Wi-Fi, LTE, WiMAX, Power Line Communication (PLC) [3, 4]. Since ns-3 is an open source software, written in C++, then it is also possible to write new modules in order to simulate new technologies and new protocols that are not implemented in the default libraries.
In this paper, ns-3 has been used to simulate how different communication technologies WiMAX, Wi-Fi and PLC may perform in smart grid applications. In case of wireless communication systems and RES production subject to weather condition (e.g. solar resource) a further detail is included, considering the influence of meteorological conditions on power production and signal transmission. Terrain orography, and the position of DERs in the network are also taken into account.
In case of optimal control applications, the MATLAB® EMS/DMS developed by the authors generates DER set-points that are sent to the relevant units. The software ns-3 elaborates the information as a data packet, before the new set points (ΔP, ΔQ) are sent to DERs for changing the network power flows, taking into account the control and communication delays, respectively Δt_{DMS} and Δt_{ICT} , and the binary parameters (α, β) that consider signal lost effects due to communication impairments.

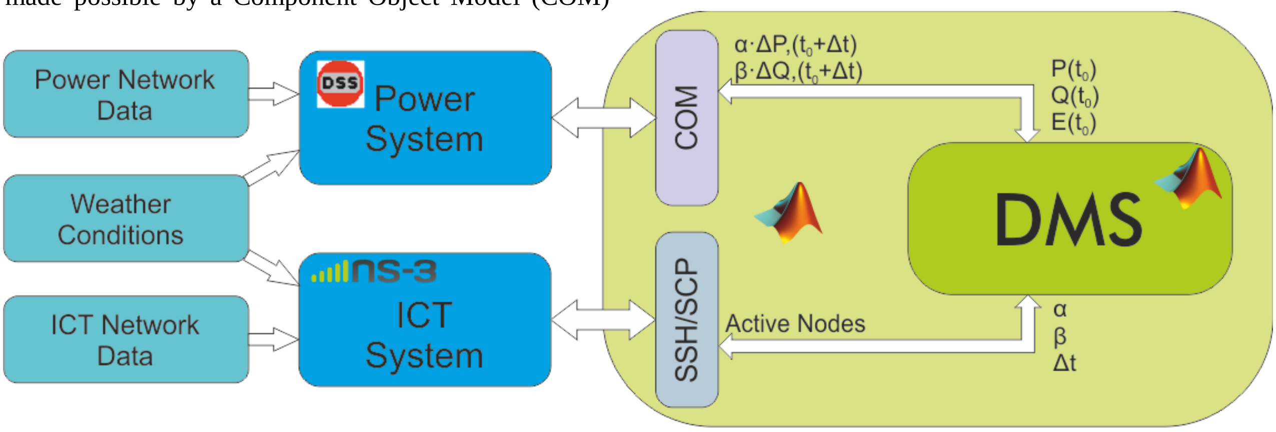

Figure 2. Architecture of co-simulation tool

Given the complexity of future Smart Grid and the need to include in the studies also the LV distribution networks, the main novelty of the co-simulation tool presented is the ability to simulate different transmission media simultaneously. In more detail, the communication infrastructure is deployed with WiMAX as the backbone of the ICT network, with the possibility of having a second technology, Wi-Fi and PLC (Power Line Communication) in cascade, that serves the smart grid at LV level.
In Fig. 3 and Fig. 4 a graphic representation of the communication network architectures adopted is reported. A WiMAX subscriber station (SS) antenna communicates point to point with the base station. The base station (BS) has the task of ensuring the two-way flow of information between the DMS and the active nodes and IED devices located in the coverage area of the BS. DERs in MV network are directly served by means of WiMAX technology. WiMAX also serves the router alongside the MV/LV substation, which is responsible for redistributing the information packet to the resources connected to the low voltage.

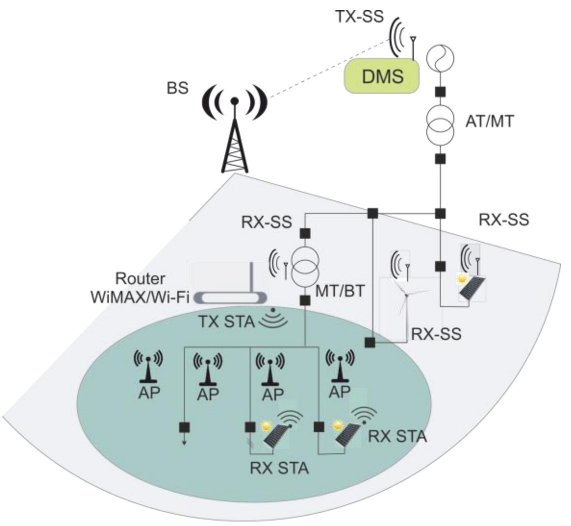

Figure 3. ICT network with WiMAX and Wi-Fi

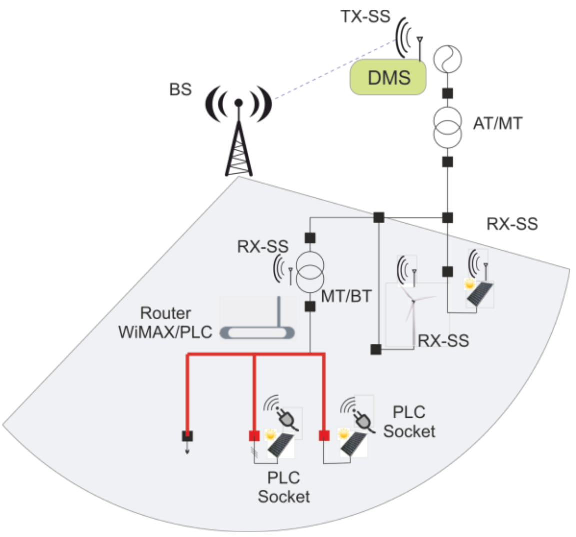

Figure 4. ICT network with WiMAX and PLC

In Fig. 3, the WiMAX+Wi-Fi infrastructure is represented. Wi-Fi network includes a number of access point (AP) and receiving station (STA). The APs have been placed at a distance of less than 100 m, in order to ensure an adequate signal coverage of the area.
In Fig.4 the network topology with PLC is shown. Each DER on the LV network is coupled to the PLC router via a PLC socket, allowing the data traffic over the transmission medium represented by the low voltage distribution network cables.

CASE STUDY

The co-simulation tool has been applied on the network shown in 5. The network considered is fed by a HV/MV primary substation, and extends globally for about 8km. The network supplies 17 MV nodes, which aggregate mixed loads and two generation plants, and a LV network through a 20/0.4 kV transformer of 1MVA with length of the feeders less than 600m.

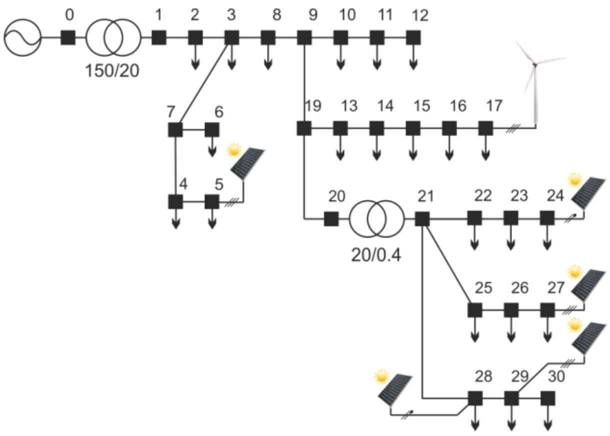

Figure 5. Scheme of the electric network studied

The profiles of loads and generators connected to the network are based on the archives of the ATLANTIDE project [5]. The total load is 3 MW on the medium voltage network, while it is 280 kW on the low voltage network. The size of the generators connected to the network are reported in Table 1.

Table 1. Generation plants connected to the network

Node	Type	Size	Voltage
5	PV	10 MVA	20 kV
17	WIND	5 MVA	20 kV
24	PV	50 kVA	0.4 kV
27	PV	100 kVA	0.4 kV
28	PV	50 kVA	0.4 kV
29	PV	100 kVA	0.4 kV

Voltage regulation application

In Fig.4 the voltage profiles of nodes N24, N27 and N29 are reported, the co-simulation tool is used to simulate voltage regulation applications. In a smart grid context, when an overvoltage is detected, it can be solved by means of an active control signal dispatching.

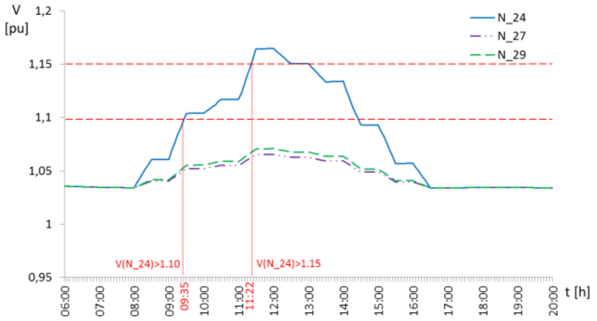

Figure 6. Voltage profiles

In this case study on active node N24 voltage exceed the threshold of 1.1 pu., and an the IED located in the node is able to detect the overvoltage and send a message to the DMS, that defines the new set points to be delivered to the DERs in the network. The new situation is depicted in Fig.7 where the power profile shows that the DMS required a generation curtailment on the PV plant @ N24, in order to solve the contingency at the node.

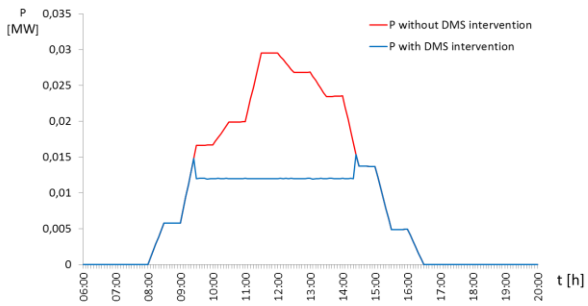

Figure 7. Power profile at node N24

A comparison for the same control with different ICT system configurations has been performed, by adopting the UDP protocol, in order to minimize the data traffic on the network, considering a data packet size of 800 bytes.
Table 2 shows the results related to the average delays that has been measured in the simulation with three different ICT configurations: only WiMAX network, WiMAX + Wi-Fi network and WiMAX + PLC network.
The WiMAX technology, and WiMAX with Wi-Fi technology in cascade have comparable performances.
It is observed in detail that this last option shows a slight growth of delays, due to the increased saturation of the WiMAX channel that transmits packets to the MV/LV router.

Table 2. Communication latencies in the active management of the power network

	WiMAX	WiMAX +Wi-Fi	WiMAX +PLC
IED-DMS	40,40 ms	45,94 ms	380.3 ms
DMS-N05	39,82 ms	45,55 ms	47.5 ms
DMS-N17	40,06 ms	43,60 ms	43.6 ms
DMS-N24	40,23 ms	50,86 ms	382.3 ms
DMS-N27	39,90 ms	57,90 ms	1317.4 ms
DMS-N28	39,98 ms	84,35 ms	2040.4 ms
DMS-N29	40,16 ms	109,43 ms	2447.1 ms

In the case of the configuration with WiMAX and PLC in cascade, a significant increase of delays when transmitting signals to the low voltage DERs is registered. It is due to the low bitrate of this technology that, combined with the CSMA protocol, determines the sequential allocation of the communication channel for every packet transmission. Although a total latency of 3 seconds is in general suitable for voltage regulation, this delay value is critical when the voltage exceeds 1.15 pu., in fact, if the overvoltage protection threshold is set according to the Italian standard CEI 0-21 [6], a disconnection of the generator from the network can occur.

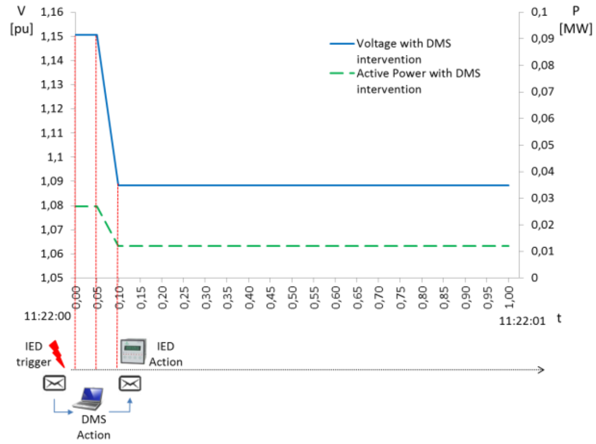

Figure 8. Power profile at node N24

Figure 9. Power profile at node N24

Fig.8 and Fig.9 show the effect of an overvoltage of 1.15pu with WiMAX + Wi-Fi and WiMAX + PLC communication system.
It can be observed that the first option guarantees a rapid intervention of the IED, with a total latency of less than 100 ms. When the WiMAX + PLC system is adopted, the total latency is 780 ms; in this case the local interface protection relay triggers at 0.2 s.
By adopting a full ICT WiMAX technology, it is possible to obtain the best performance in terms of transmission delays whereas a WiMAX + PLC infrastructure reveals delays that are compatible with slow dynamics intervention such as voltage regulation, although the low bitrate of narrowband PLC does not ensure rapid intervention in critical conditions (e.g over voltages over 1.15 pu). Finally, the arrangement WiMAX + WiFi appears as a good compromise, given the low cost of the Wi-Fi technology combined with its high performance.

CONCLUSION

The paper has presented a tool for co-simulation of SDN which can be used to simulate active management with slow dynamics, such as voltage regulation and the management of power flows in the networks for solving congestions. A comparative analysis of the different ICT architecture solutions for active management has been performed with the presented tool, in order to measure their performances in terms of latencies and examine the suitability for smart grid applications The tool is also useful to simulate the dynamics on the power system in case of RES disconnections due to protection intervention.

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