



**FLEX<sup>e</sup>**



Future Energy  
System

RESEARCH REPORT  
NO 1.1-10  
HELSINKI 2015

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Repo**

# **D1.1-10 Power System and Communication Network Real- Time Co-Simulation Environment**



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ISBN XXX-XX-XXXX-X  
ISSN XXXX-XXXX



## CLIC Innovation Research report no 1.1-10

# D1.1-10 Power System and Communication Network Real-Time Co- Simulation Environment

## Preface

This report was done as a part of the Finnish national research project "Flexible Energy Systems" FLEXe, and it was funded by Tekes, the Finnish Funding Agency for Technology and Innovation, and the project partners. The report was written by Tampere University of Technology and VTT.





**Name of the report: D1.1-10 Power System and Communication Network Real-Time Co-Simulation Environment**

**Key words: Real-Time simulation, Communication emulation, Hardware-in-the-loop, Software-in-the-loop**

## Summary

The development of electricity distribution network in to a smart and flexible system that enables increased amount and more adaptive control of resources requires more complicated automation systems to be able to operate adequately and safely. The development process of such novel distribution automation system benefits greatly if the functionality of the concept can be evaluated in controlled test environment prior to taking it out to an actual distribution network for field testing.

This report describes the implementation of a real-time simulation environment, which integrates communication network emulation to real-time power system simulation and software- and hardware-in-the-loop testing of network monitoring and control devices. The document provides an introduction to different sectors of the simulation environment and through an example use case the functionality of the system is demonstrated.





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## 1 Introduction

Testing and evaluating proper functionality of a distribution automation architecture in controlled environment is a vital part of the development process before taking the system out to the field. The system needs to be reliable and proven to be operating like intended in order to securely handle the distribution network.

This report describes the integration of a communication emulator in to an existing test environment at TUTs Real Time Digital Simulator (RTDS) laboratory. The existing laboratory set up has been used to test a decentralized distribution automation concept and includes real time simulation model of a distribution network, substation automation units and physical IEDs connected as hardware-in-the-loop test devices. With that system it has been possible to evaluate the functionality of a distribution automation system with both hardware- and software-in-the-loop testing, but the communication between automation system entities has been rather ideal while realized over an Ethernet based laboratory LAN.

With the communication emulator it was possible to extend the test environment to take also different communication methods into consideration, for example between substation automation unit and smart meters located at customer end. This document gives an introduction to the functionalities of the emulator as well as the test set up at the RTDS-laboratory and finally the operation of the system is demonstrated with a low voltage distribution network congestion management use case.





## 2 Test Environment

The co-simulation environment at Tampere University of Technology consists of a Real Time Digital Simulator (RTDS), communication emulator, substation automation unit (SAU) and physical control and monitoring IEDs. Following chapters introduce all different parts of this test environment in detail.

### 2.1 Communication Emulator

The Communication emulator is an Ethernet switch with added functionality to emulate slower and less reliable (than Ethernet) communication paths for the selected packet flows. The flow selection is based on source and destination addresses and port numbers (for UDP and TCP). The throttling and downgrading the flow is activated by attaching a profile to the flow. A profile consists of following parameters:

- **Bandwidth up and down** [Kbps] sets the emulated bit rate. The two values (up/down) are needed for a communication path where the bit rate is different depending on direction of the flow. In such case, the user must indicate the flow direction manually, because the emulation device cannot know the direction.
- **Delay** control adds a delay to the flow. The delay for each packet is computed from three parameters: base delay [ms]  $\pm$  variation [ms] and correlation [%].
- **Packet loss** setting causes random drops for packets. The loss probability for each packet is computed from two parameters: loss [%] and correlation [%].
- **Packet duplication** setting duplicates random packets. The duplication probability is given as percentage value.
- **Packet corruption** setting adds random errors to packets. The corruption probability is given as percentage value.
- **Packet reorder** setting causes random reordering to some packets in the flow. The reordering probability is given as percentage value. For the reordering to work, the profile must also specify a non-zero delay.

The system consists of following components:

- The emulator is a computer with two or more Ethernet interfaces and running a version of Ubuntu. All Ethernet interfaces are bridged together, providing the basic Ethernet switch functionality. In test environment this hardware was a Lanner FW-7543, with 4 Ethernet ports.
- This computer also runs the emulation management software controlled by a browser based graphical UI. The software consists of two python scripts: packet.py performs the packet sniffing and controls the application of profiles to flows using Linux netem services; server.py provides a web server for the GUI components.

A simple setup of the emulation using the GUI on browser (<http://<emulator-ip>:8080/>) requires the following steps:





- Build the set of emulated flows from sample of sniffed packets seen by the emulator: select packets from sniffed list into filter list, and then in the filter section optionally mask away unnecessary parts flow selectors depending on the desired traffic to match. The constructed filter list can be saved and reused in later sessions.
- Choose a profile for each flow. The system comes with predefined example profiles: **3G**, **Ethernet**, **GPRS**, **LTE** and **xDSL**. These profiles can be modified using the GUI and saved with same or a new name (creating a new profile).
- A completed filter with profiles can be activated (Run) on the emulator and defined profiles take effect on the flows that match the filter, while all other unmatched traffic through emulator is unaffected. Deactivation (Stop) removes all profiles from the emulator, and all traffic goes through at full speed.

## 2.2 RTDS Simulator and Distribution Automation System

A novel network control architecture based on a decentralized concept is proposed in [1] has been used as an example to represent the testing of complete automation architecture and system testing utilizing integrated HIL and SIL testing methodology. The distribution network automation hierarchy is divided into primary, secondary and tertiary control levels which all operate on different network layers and have different operating time scales. The primary level includes IEDs, such as controllers and protection devices, which are operating autonomously and respond fastest to any disturbances or changes in the network. Primary devices monitor and control locally the point of network where they are connected to, for example voltage control with transformer on load tap changer (OLTC) control or reactive power control of a DER.

The simulation arrangement is presented in Figure 1 for the low voltage network and secondary substation automation unit (SSAU). The lab infrastructure includes the RTDS simulator, actual physical IEDs, communication emulator, equipment needed to interface the IEDs to the RTDS and prototypes of the SSAU.





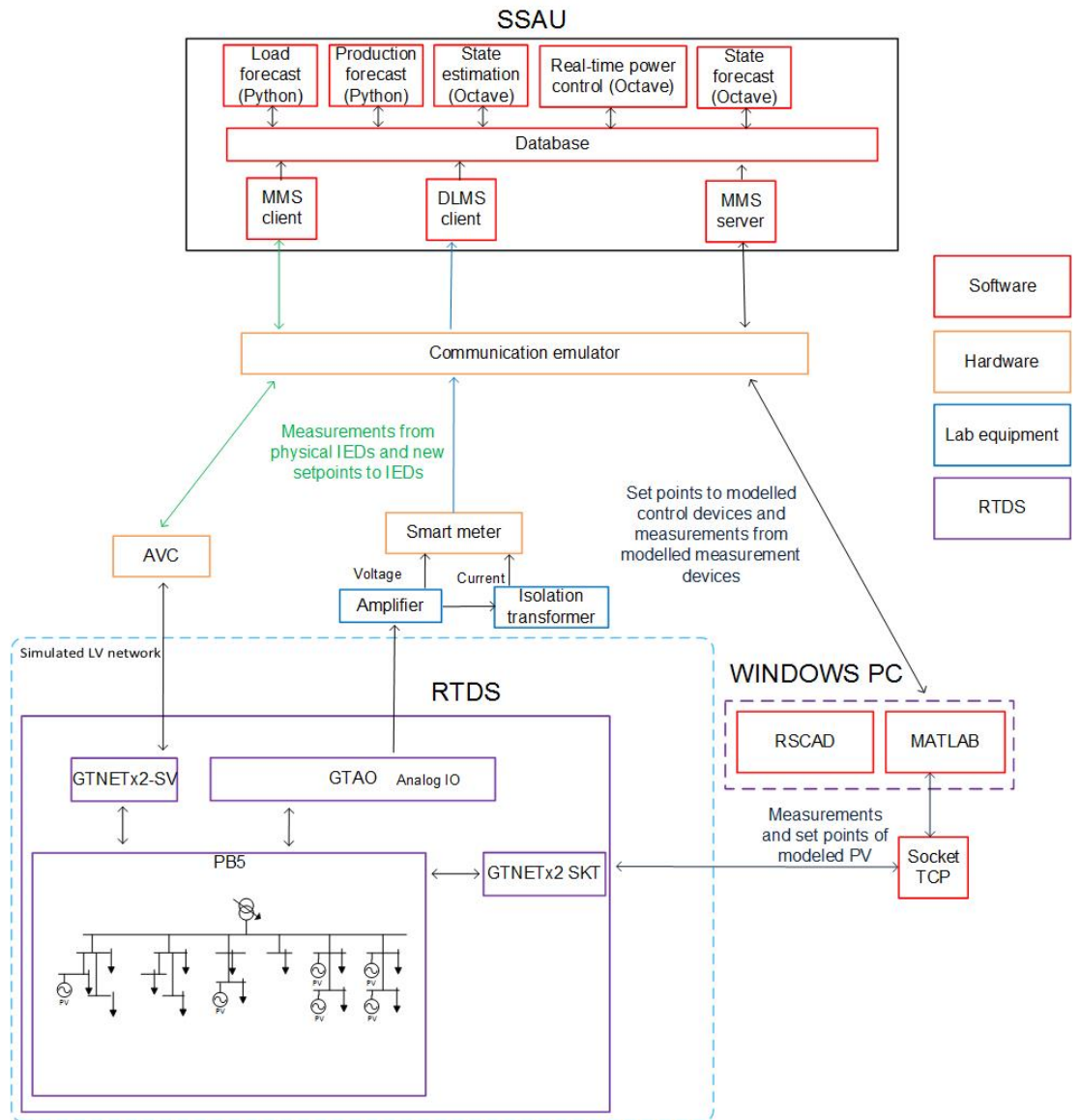


Figure 1 Laboratory arrangement for the communication emulator testing.

Several I/O interfaces and communication protocols has been used in the test set up to make it more versatile. IEDs included in the simulation are an OLTC automatic voltage controller (AVC) at the secondary substation, a smart meter located at one customer point as well as simulated DER control devices and secondary substation measurements. The AVC relay receives from the RTDS phase voltage measurements from the secondary side of the main transformer as IEC 61850-9-2 Sampled Value transmission and the position of the on load tap changer as digital signal. If necessary, control signals from relay to RTDS are delivered as digital signals in order to raise or lower the tap changer position. The relay is fully based on the IEC 61850 standard and it delivers measurements to the client at SSAU and receives possible new operating set points from it through IEC 61850 MMS protocol.





The other physical IED is a typical household smart meter that is connected directly between feeding network and load, but since there is no actual load at the laboratory it requires an isolation transformer to create proper load current. In practice the voltage from the amplifier is fed directly to the input terminal of the meter while current is fed through a transformer with a turn ratio of 10:1 to produce a higher load current which is then connected to the same input terminal as the voltage. This arrangement does not over load the amplifier and creates a floating load current for the meter. In addition to connecting real IEDs with RTDS, this demonstration uses TCP/IP Socket to directly interface RTDS to SSAU in order to deliver measurements from the simulation. This is realised by GTNET-SKT with GTNETx2 network communication cards of the RTDS. Via TCP/IP Socket, real and reactive power measurements of simulated PV plants as well as all low voltage network feeders are sent from RTDS to the database at the SSAU computer. TCP/IP Socket interface is also used to deliver new operational set points to simulated PV units.

In this case also the communication emulator has been added between all the IEDs, physical and simulated, and the SSAU interfaces. Couple of different communication modes were used for different IEDs to test the versatility and durability of the emulator and to provide evidence of the emulators suitability for test environment with several connection points. More information about the testing of the distribution automation architecture used in this document as well as testing of the laboratory set up used partly in here can be found from [2].

The simulated network is a reduced low voltage distribution network with six feeders and customer points on each feeder as well as six DG units on four different feeders. The network had to be reduced from the actual network topology due to RTDS's limitation of network nodes to 90. The reduction was done according to nominal loading data received from the DSO by combining loads and line parameters. [3]





### 3 Use Case: Congestion Management of LV Network

In order to prevent unwanted voltage rise caused by DERs and to increase the DER hosting capacity in weak distribution network some physical changes could be done, such as increasing the conductor size. This, however, is often expensive and may cause network components to be replaced before the end of their useful timespan. Other option is to utilize sophisticated distribution automation system that enables real time active network management. The active network control takes advantage of extensive real time network monitoring to define necessary control actions in order to prevent congestion in the network. The control of the network can use several controllable resources in the network, such as tap changer controllers and DER reactive power controllers.

Congestion management is essentially divided into three different hierarchical levels, primary, secondary and tertiary, which operate on different levels of the network and with different operating cycles. The fastest control is the primary control and it is realized with local control devices, which manage network conditions locally according to their settings e.g. by regulating the reactive power level of PV unit. Secondary control is located at the secondary or primary substation, depending on the network section it is controlling. It is slower to react than the primary control, but it has a broader vision of the network state and coordinates all the primary devices accordingly to minimize operational costs of the network.

Tertiary control is usually located at the control center and it provides day-ahead production and loading scheduling based on state estimates and forecasts. It also combines economical aspects to the network management. The focus of the laboratory tests here is the primary and secondary network control of a LV distribution network.





## 4 Test and Results

The actual test simulation included a simulation script ran both without the emulator being activated and with the emulator affecting the communication between SSAU and IEDs. The simulation script was a quite simple ten minute run where the network state is kept constant for the 2.5 minutes when the production of all six DG units in the network was decreased by 70%, at 5 minutes the loads in the network are increased to 2.5 times the original and at 7.5 minutes the production is brought back to the same level as in the beginning while the load conditions stay at the increased level. The communication parameters used in the emulator can be seen in Table 1.

**Table 1 Parameters used in the emulator for different IEDs.**

PARAMETER	AVC RELAY	SMART METER	SOCKET TCP/IP
COMM. SERVICE	Ethernet	GPRS	LTE
BANDWIDTH	↑↓ 100Mbps	↑↓ 60 Kbps	↑5000 Kbps↓15000Kbps
DELAY	0.25±0.25 ms	350±100 ms	7.5±5 ms
PACKET LOSS	0%	0.5%	0.025%
DUPLICATES	0%	0.1%	0%
REORDER	0%	0.2%	0%

The communication service for the AVC relay was chosen to be Ethernet based, since it would be physically located close to the SSAU at the secondary substation. The smart meter is located further away from SSAU and connected likely through 3G or GPRS network, from which GPRS was chosen to be more likely to result to some effect on the functionality of the system. Socket TCP/IP is quite different case, since it delivers measurements from both secondary substation feeders and DG units located around the simulated network. These measurements cannot be treated individually by the emulator, since they are transmitted as one package. The LTE service was chosen to have some constraints on the communication and to test the operation of the emulator with several different filters. The Socket has very little to do with real life applications and for example 3G service would have already been too slow for the vast amount of measurement data transmitted with the Socket. The effect of the communication filtering with the emulator to the coordinated voltage control and network minimum and maximum voltages can be seen from the



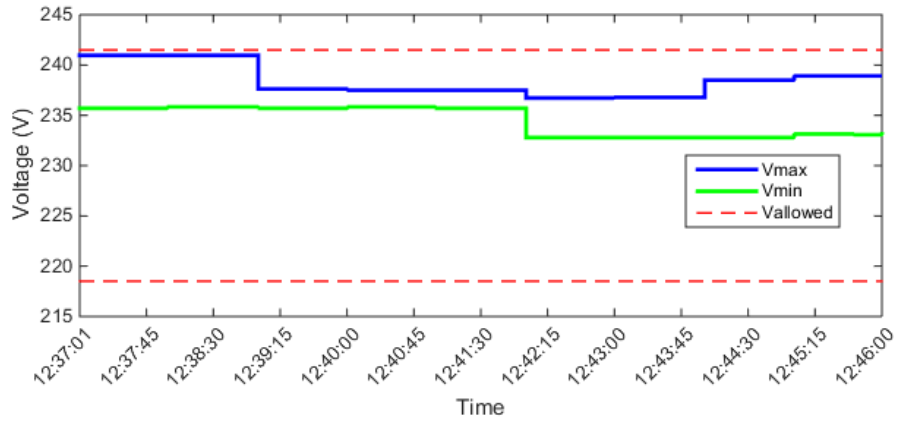
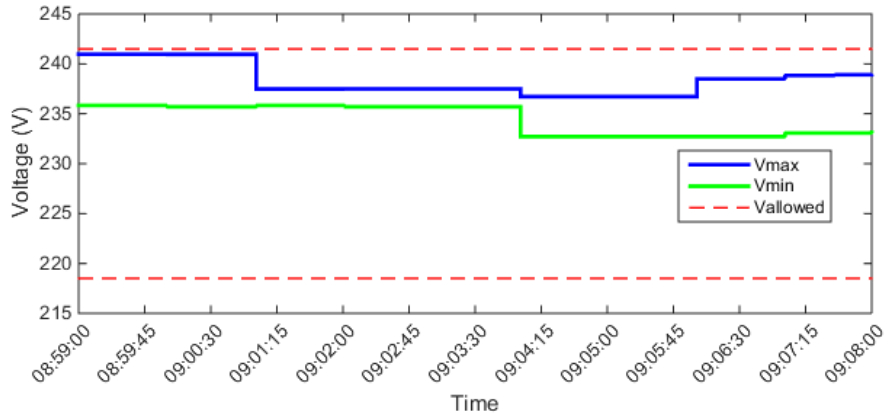


Figure 2.



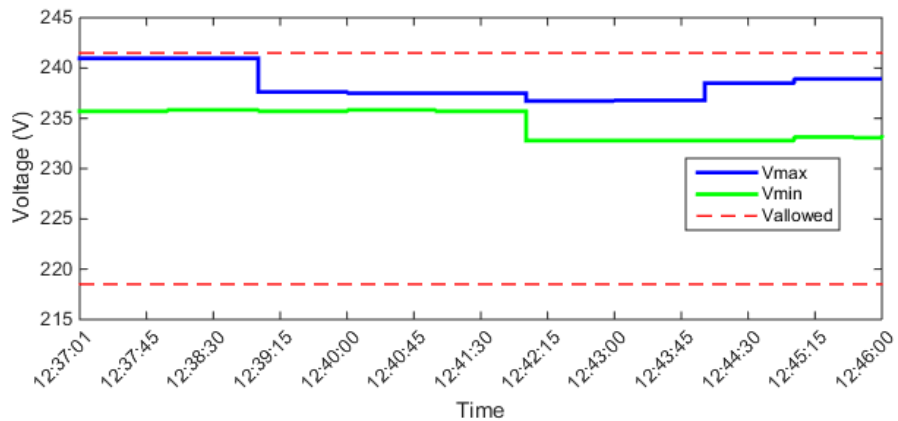


Figure 2 Maximum and minimum voltages in the network without the communication emulator and with the emulator connected between IEDs and SSAU.

From the beginning it was clear that the use of the emulator on this type of decentralized distribution automation concept and laboratory set up would not have significant, if any, impact on the operation of the congestion management. This situation is clear from the

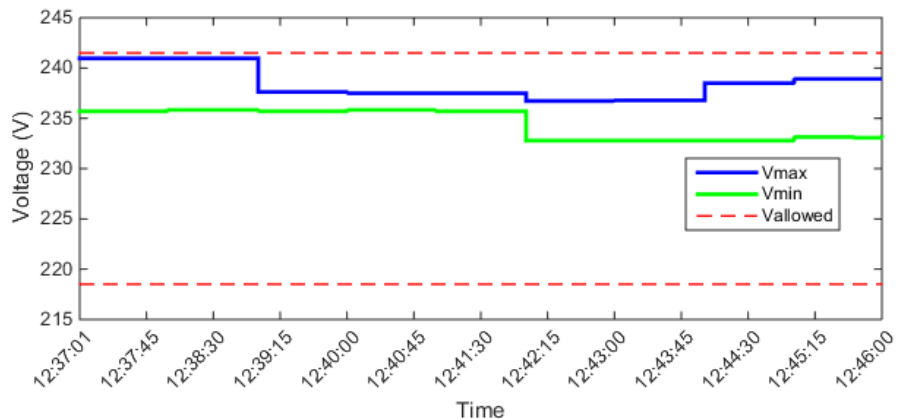


Figure 2 where maximum and minimum voltage in the network is shown with allowed higher and lower limits. If the two different graphs are observed really closely some very minor differences can be seen on voltage profiles between the two cases. The next Figure 3 presents reactive power levels of each DG unit in the network.



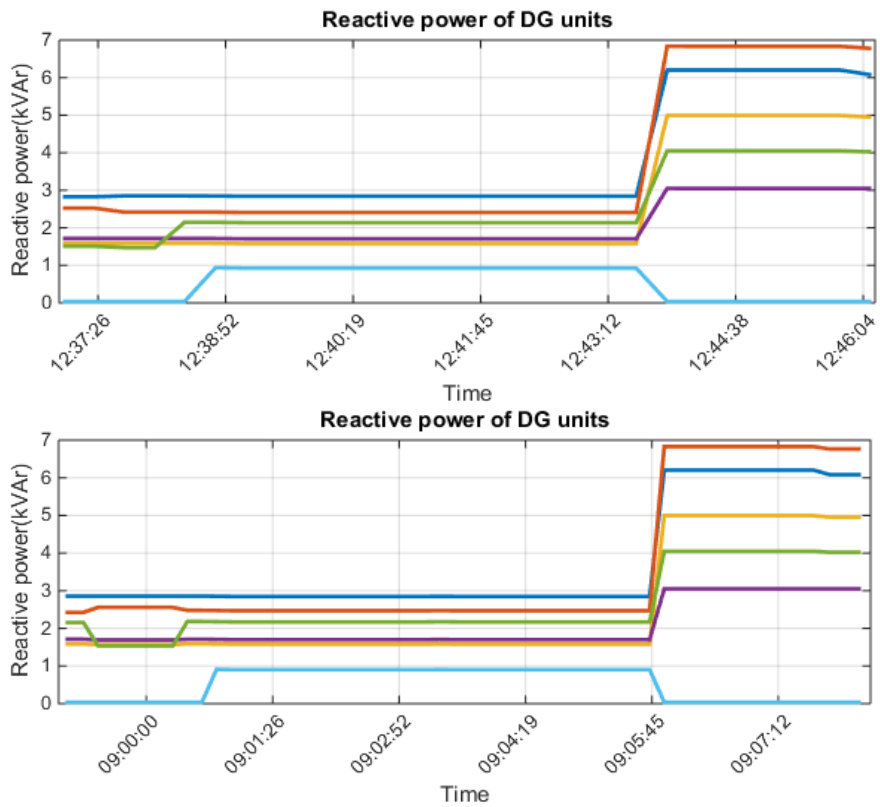
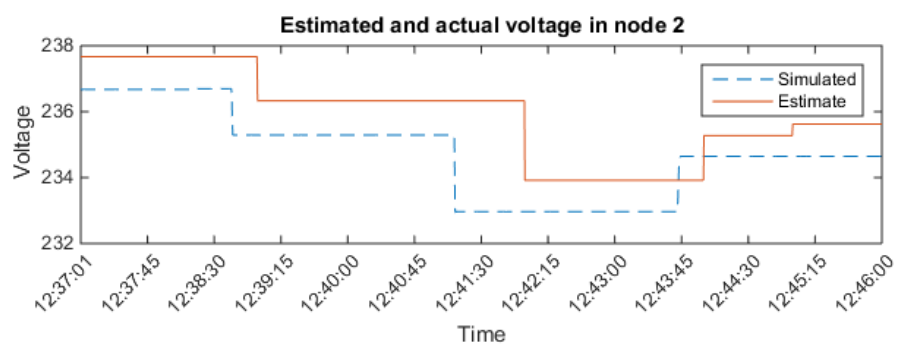
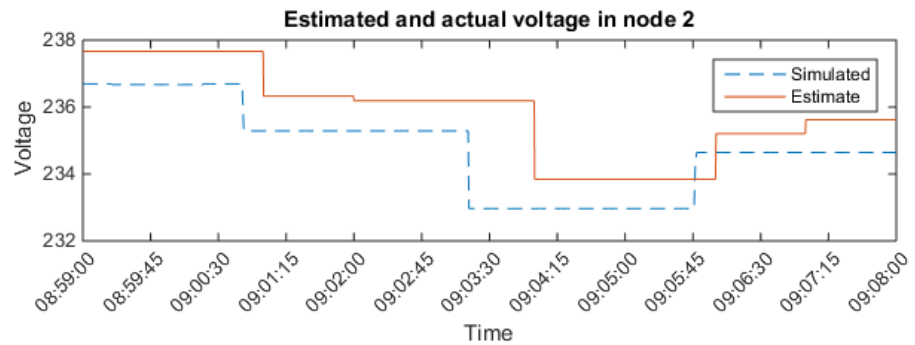


Figure 3 Reactive power levels of DG units in both situations.

In these two graphs some more obvious differences can be found, but still the overall pattern of the reactive power level control of DG units is very similar. In the original simulation case with no communication constraints there are few control actions more than in the one with the emulator. This could be because of the delay in the Socket interface, since that transmits measurements from the DG units as well as delivers new reactive power set points for the DG units. The impact on the state estimation was also studied and example result for one node can be seen in [Figure 4](#).

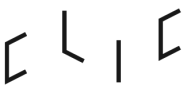




**Figure 4** The voltage estimate and the actual value in the simulations for one network node in both cases.

Also in the case of state estimation accuracy there is practically no difference between the two simulations. Although the emulator was successfully integrated to the laboratory test environment it did not have any effect on the operation of the distribution automation system in question. However, the emulator proved to be capable of operating in such conditions and provide versatile communication traffic filtering between various devices at the same time.

This test showed mainly that the developed automation architecture and use cases are very robust and are not affected by occasional communication interruptions, e.g. missing or delayed packages, and general bandwidth limitations or delays. In order to accurately study impacts of the communication filtering to the system the focus should be on the real time monitoring of the network, since that is the most likely to have any issues. This would require new automation- and key performance indicators (API, KPI) to be defined that take these things in to consideration.







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