Real-Time Simulation of small-scale power grids with software in-the-loop and hardware in-the-loop experiments

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INTRODUCTION

As the term "Smart Grid" defines, the electricity supply network uses smart devices to monitor the state quantities, and digital communication technologies to support fast decisions and control. This work is focused on developing a flexible IoT architecture to support real-time tests and to validate some algorithms for monitoring and maintenance of micro-systems as intelligent smart functions on the virtual model of a small-scale power grid, through Real-Time Simulation Software in-the-loop (SIL) and Hardware in-the-loop (HIL).

We aim to explain the implementation aspects of a microgrid in MATLAB/Simulink, based on real grid data and "smart customers" as end-users (capable of exchanging data with the outside of the simulation environment), then compiled in Real-Time environment (RT-LAB software) [1]. The overall communication infrastructure relies on different protocols for the data exchange between grid and application components (TCP and MQTT protocol). Furthermore, the presence of an MQTT broker makes the architecture flexible, since it allows the integration of different services.

OVERALL ARCHITECTURE

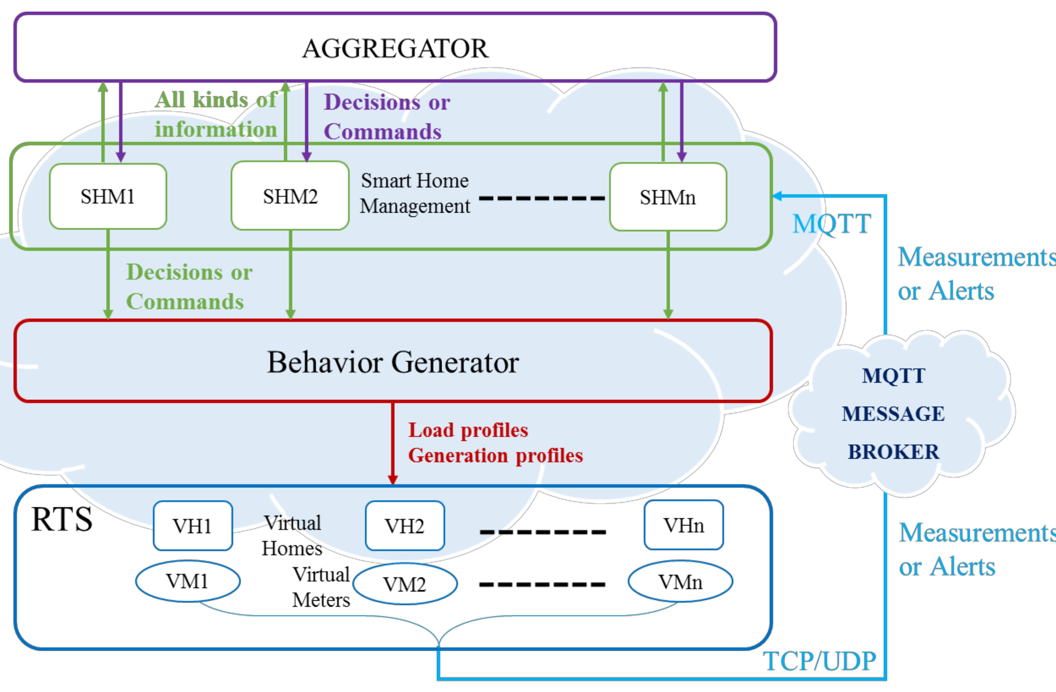

Figure 1. Overall architecture for the proposed implementation

Figure 1 shows all the levels involved in the development process of the proposed study case. At the lowest level, a real time simulation of a real MV/LV grid is performed using Opal-RT to better evaluate the way in which the behavior of various consumers/prosumers affect the performance of the power grid in terms of voltage profile, overloads or quality of supply (harmonics, frequency, etc.)

A consumer/prosumer behavior model is used, and data is sent to the real-time simulator by means of a dedicated block.

All relevant data are sent by Opal-RT to a MQTT Cloud Broker via TCP/IP protocol and then is integrated in the upper level of the proposed model in real time to the server and then to the SHM and Aggregator (Figure 1 and Figure 2).

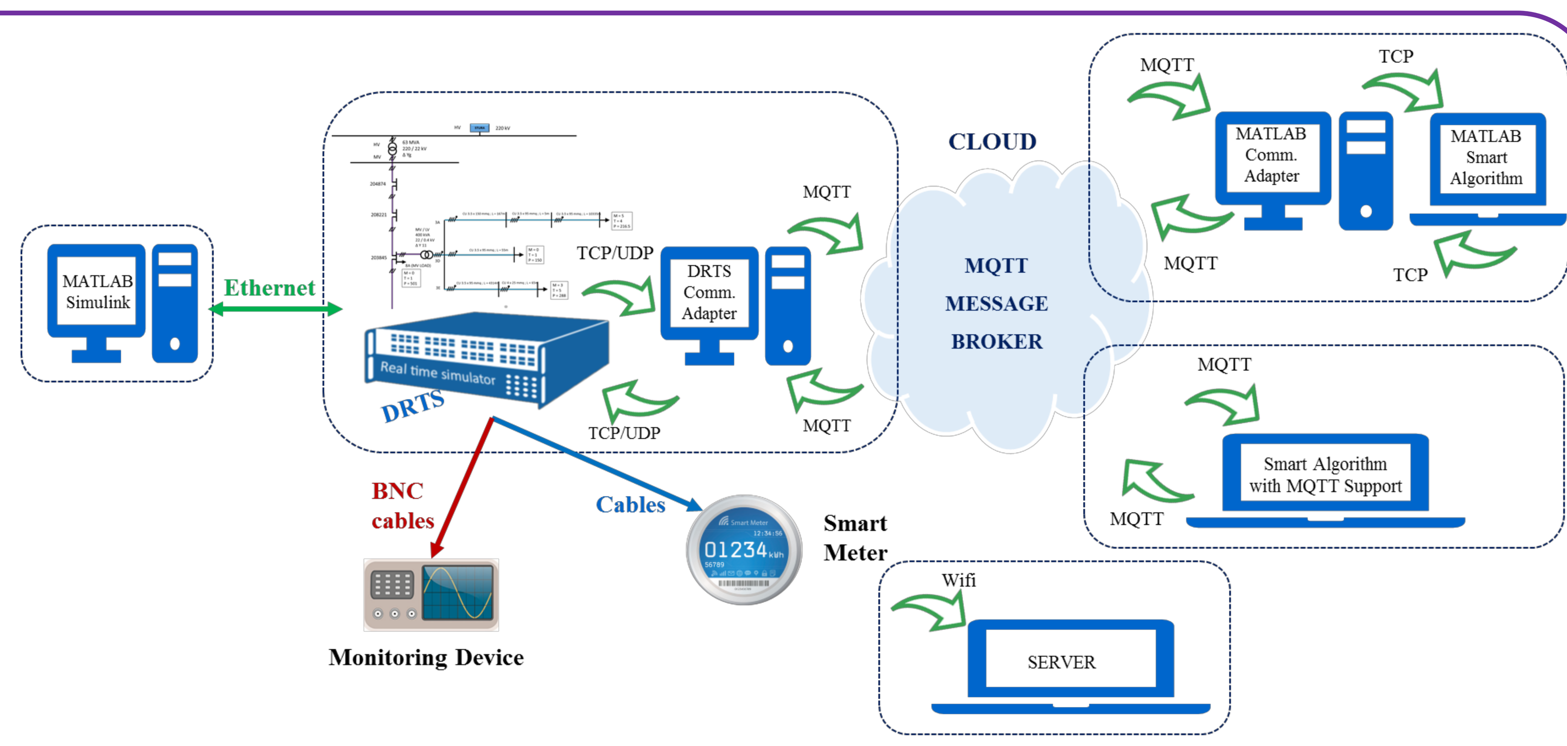

Figure 2. Explicit overall architecture

MODELLING OF THE SMALL-SCALE LOW VOLTAGE GRID

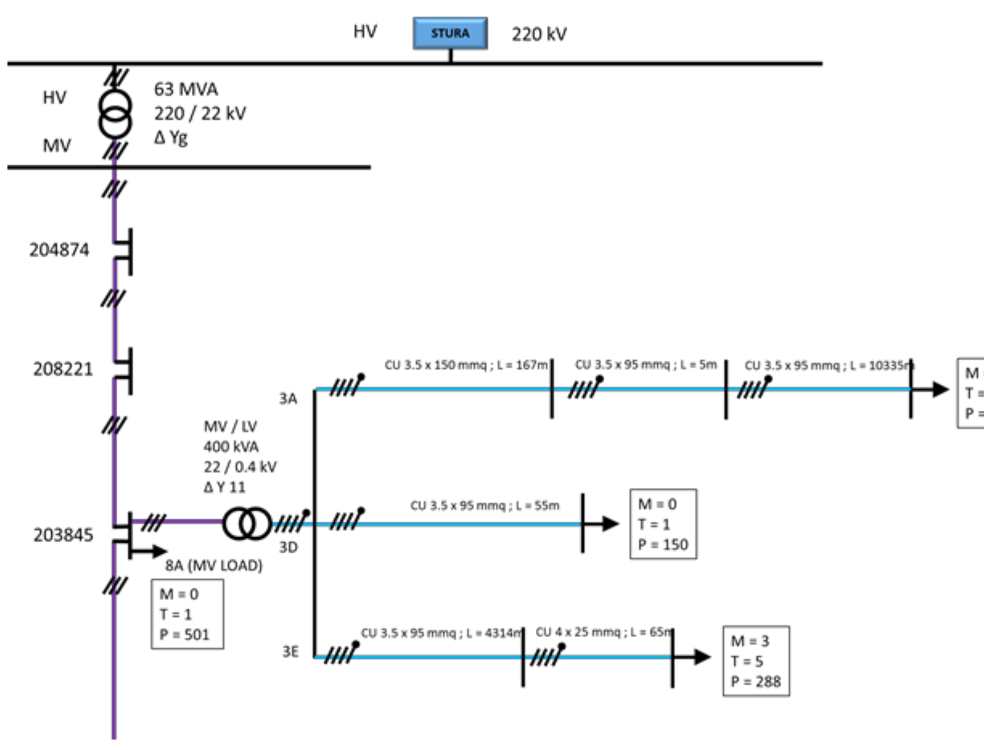

Figure 3. Modelled distribution system topology

In this scenario, a small-scale distribution system of the future, where there is a high penetration of Smart Meters, with bidirectional communication, is under study. The system is investigated during a normal day, with normal consumption/generation behavior. The consumers (8 LV households) with "Smart behavior" were modelled using data from real houses (Figure 4). Additionally, there are 11 LV 3-phase industrial loads (Figure 5 and figure 6) with and 1 MV industrial load.

Each house was equipped with "Virtual Smart Meters" to monitor their consumption and behavior, in terms of Voltage, Current, Active and Reactive Power.

Table 1. Small-scale system summary

Total number of buses	15
Total number of lines	11
Total length of MV lines	5.53 [km]
Number of MV customers	1
Total number of single phase LV customer	8
Total number of three phase LV customers	11
Total contractual consumption	1000 kW

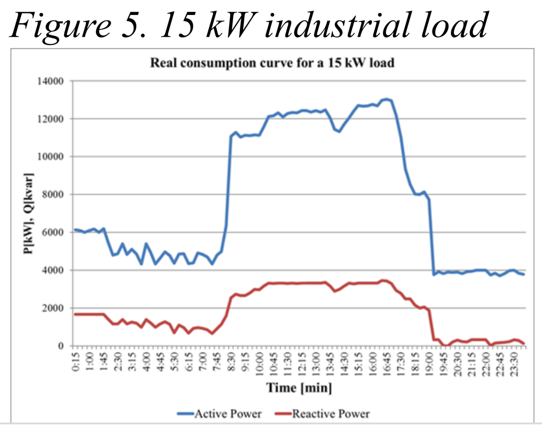

Figure 5. 15 kW industrial load

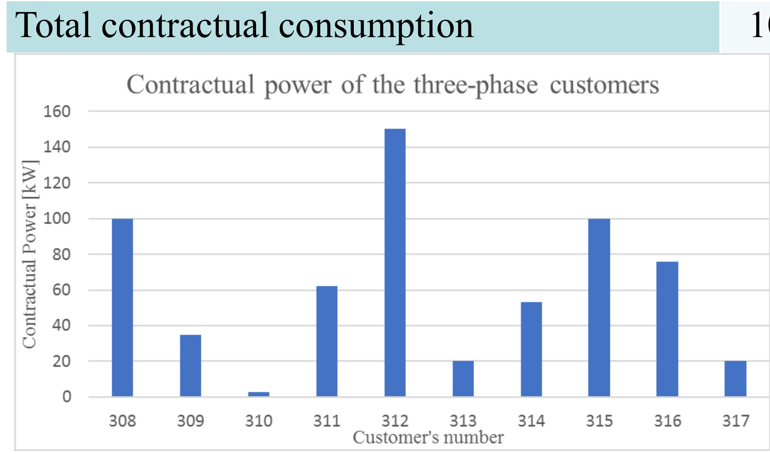

Figure 4. Contractual power single-phase customers

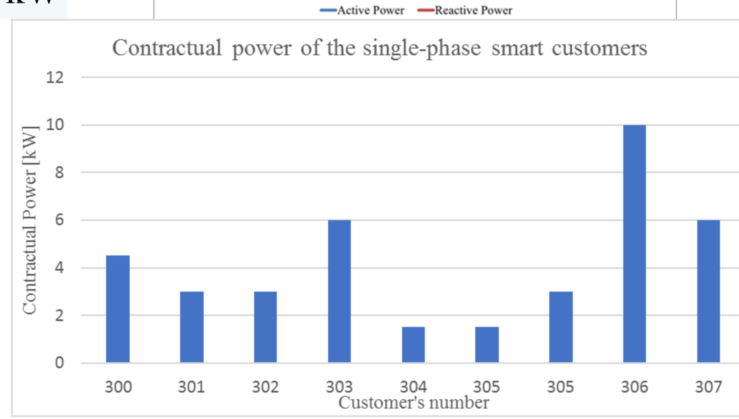

Figure 6. Contractual power three-phase customers

SOFTWARE IN-THE-LOOP

Figure 7. Bidirectional communication architecture

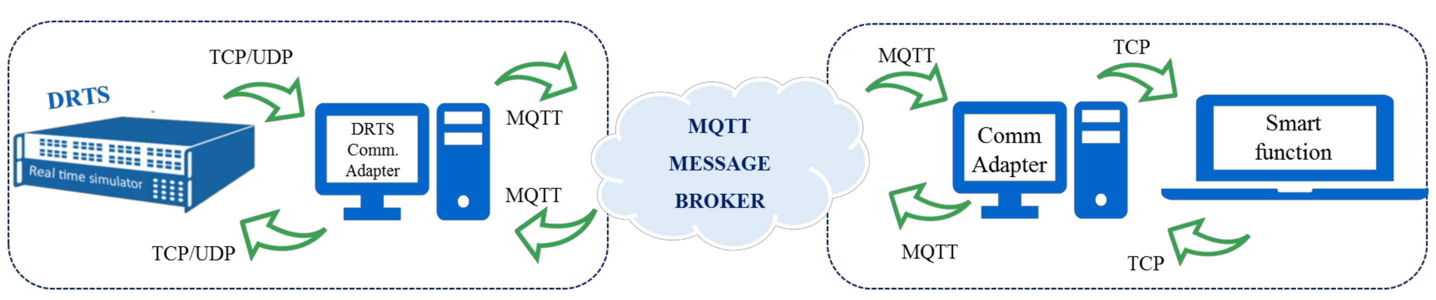

Figure 7 shows that the flow of information is bidirectional: data from the RTS to the smart function and vice versa. A stream of data for each house/customer was created. The server adapter exploits a parser (a Python script) to translate the array into a more verbose json format, compliant with the IoT platform Fiware [2], to be published towards the MQTT broker. MQTT is a publish/subscribe messaging protocol that ensures flexibility in communication.

A smart function is implemented into the Smart Home Management (SHM) to receive, store and send data to an Aggregator, where other functions and smart algorithms might be deployed for DMS purposes. The Aggregator formulates and sends commands and decisions to each SHM, then to the Behavior Generator, and finally all the commands (but in our case only consumption/generation profiles) will be passed to the simulator to further assign to each virtual house in the implemented grid (as shown in Figure 8).

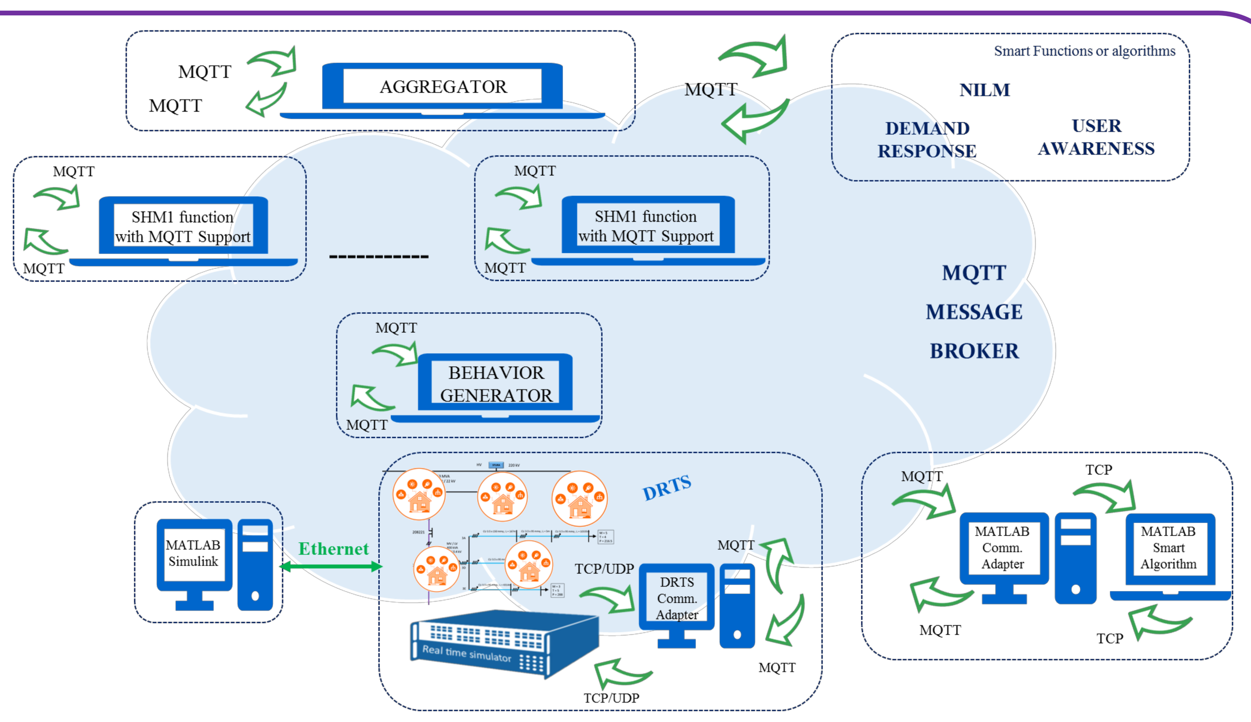

Figure 8. SIL overall architecture

SMART METER IN-THE-LOOP

The smart meter used in this work is based on a Raspberry Pi that ensures: i) synchronization with all its hardware components and ii) communication with a remote server for saving data. This smart meter is connected to DRTS following the HIL simulation approach. It measures the electrical power of a virtual house. Theoretical schematics of the HIL simulation is presented in Figure 10. The simulator outputs two signals corresponding to the voltage and current consumed in real time by one of the houses. The smart meter is connected to the real-time simulator and receives directly those analog signals. The acquisition board was configured in such a way to create a stream of data (to be then sent by the Raspberry Pi to the desired remote server) in a certain way. To store and visualize the information, a database was properly created.

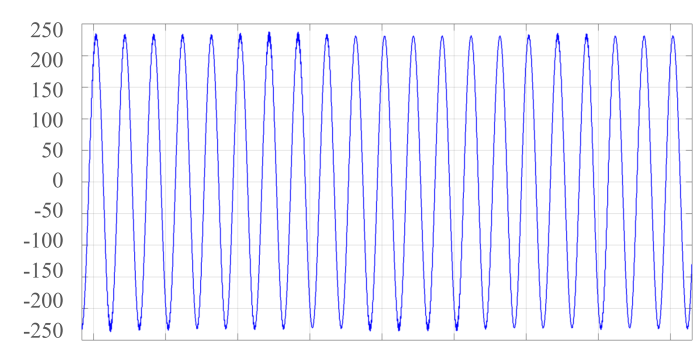

Figure 10. Voltage wave (RMS values)

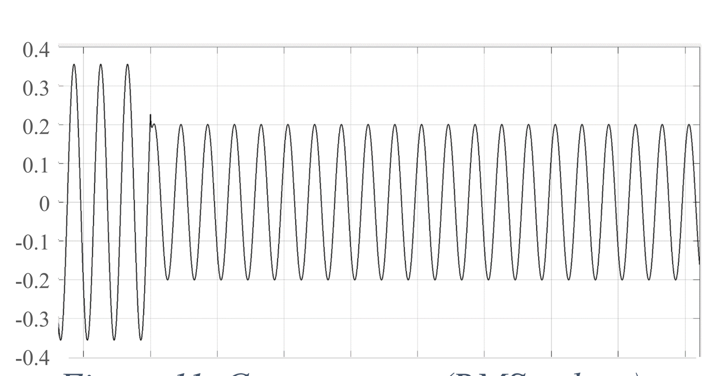

Figure 11. Current wave (RMS values)

ID	TIME	VOLTAGE	CURRENT	ACTIVE POWER	REACTIVE POWER	APPARENT POWER	POWER FACTOR
111	2018-06-12T10:37:07.812641	225.079	0.003	-0.573	-0.07	0.774	-0.744
112	2018-06-12T10:37:09.096200	238.446	0.004	-0.478	-0.107	0.835	-0.577
113	2018-06-12T10:37:10.383114	224.189	0.004	-0.542	-0.192	0.853	-0.639
114	2018-06-12T10:37:11.672559	228.033	0.004	-0.612	-0.228	0.853	-0.721
115	2018-06-12T10:37:12.956294	238.228	0.004	-0.57	-0.271	0.95	-0.603
116	2018-06-12T10:37:14.262833	224.374	0.004	-0.67	-0.32	0.95	-0.708
117	2018-06-12T10:37:15.533820	231.74	0.004	-0.737	-0.344	0.981	-0.755
118	2018-06-12T10:37:16.806374	238.343	0.005	-0.704	-0.369	1.085	-0.652
119	2018-06-12T10:37:18.082621	231.955	0.005	-0.716	-0.375	1.103	-0.652
120	2018-06-12T10:37:19.356457	232.791	0.005	-0.89	-0.405	1.139	-0.783
121	2018-06-12T10:37:20.686207	237.409	0.005	-0.835	-0.393	1.206	-0.694
122	2018-06-12T10:37:21.976564	230.056	0.005	-0.917	-0.393	1.212	-0.759

Figure 12. Database containing simulation results

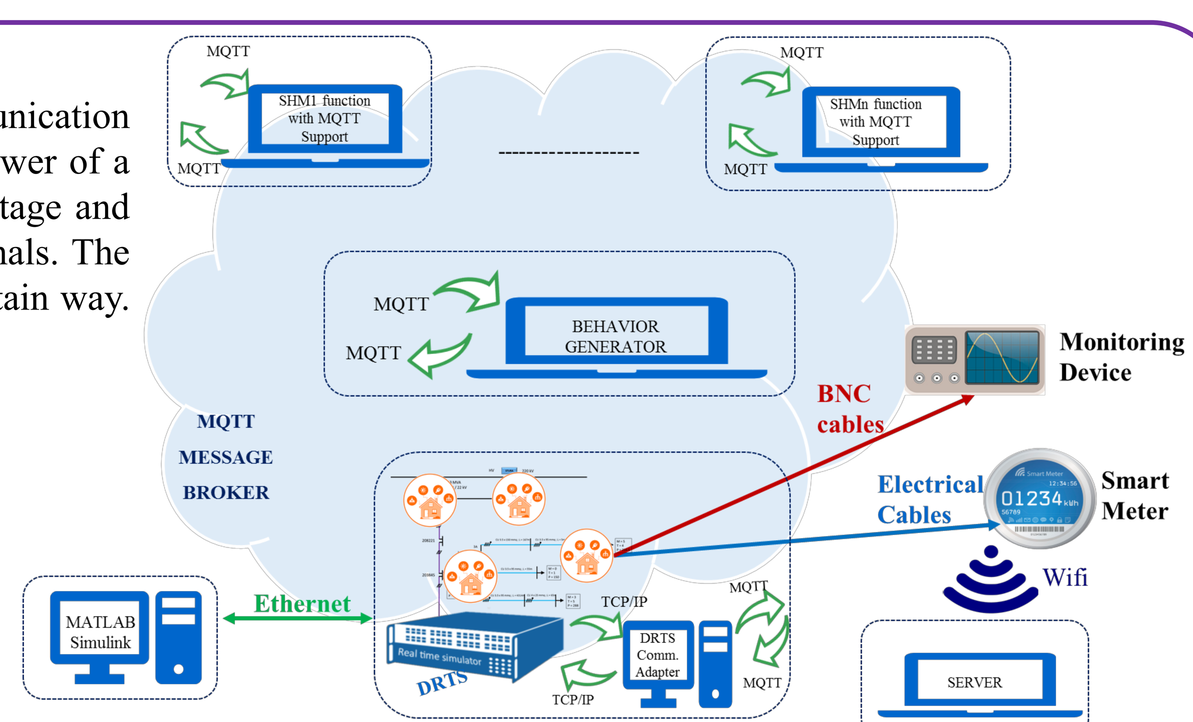

Figure 9. HIL simulation

CONCLUSIONS AND FUTURE WORK

- A flexible IoT oriented architecture was created and tested with the aim to support tests and validations of different algorithms over virtual model of the grid, based on information coming from the customer side or grid
- SIL simulation enables development of future smart algorithms
- HIL simulations were performed (with a smart-meter) in order to measure the voltage and the current (then compute the powers), and the resulting data to be sent to a local server;
- The optimization and standardization of the data communication between different layers of actors as future step is developed;
- Future development of smart and adaptable interfaces for DMS is intended;

REFERENCES

[1] https://www.opal-rt.com/
[2] https://www.fiware.org/