HIGH PERFORMANCE VIRTUAL GENERATOR BESS FOR DISTRIBUTION SYSTEMS SUPPORT APPLICATIONS ANALYSED IN A HARDWARE-IN-THE-LOOP SIMULATION SET UP

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ABSTRACT

Battery Energy Storage Systems (BESS) are becoming more and more popular to address some of the challenges that distribution systems are facing. The key BESS applications revolve around traditional topics such as deferring grid extensions or novel predicaments due to increased integration of non-dispatchable renewables on the grid edge. This paper provides an insight into the BESS solution design and engineering process and demonstrates a selection of use cases in a hardware-in-the-loop (HIL) simulation set up.

INTRODUCTION

Recently more and more Distribution System Operators (DSO) have started to utilize Battery Energy Storage Systems (BESS) to address some of the challenges that they are facing [1], [2].

The drivers are diverse, BESS solutions can provide fast power injection and also allow for energy time shifting, hence increase end user power quality and improve the distribution infrastructure reliability and resiliency.

ABB PowerStore^{TM} is a mature and reliable product that provides the full benefit of the battery storage technology. Maximum value for the owner of the BESS is created by an optimized design and sizing of the storage system paired with an automation solution that allows for multiple revenue streams.

TORSEBO PROJECT

The Vattenfall R&D project, “Network Micro-grid Torsebo Demo” aims at implementing and studying microgrids in the distribution grid. The project’s main focus is to assess how or whether microgrids can be used in MV/LV network to help improve voltage quality, increase reliability and improve hosting capacity of DERs and at what cost.

The Torsebo microgrid, schematically depicted in Figure 1, is composed of:

- Six non-controllable loads (aggregated peak load of 37kW and reverse power peak: 38.2 kW).
- Two non-controllable PV units (25 and 18 kW);
- One ABB PowerStore^{TM} BESS unit (90 kVA / 57.1 kWh).
- One ABB Microgrid Plus control system supervising the low voltage grid and with control capability over the storage unit.

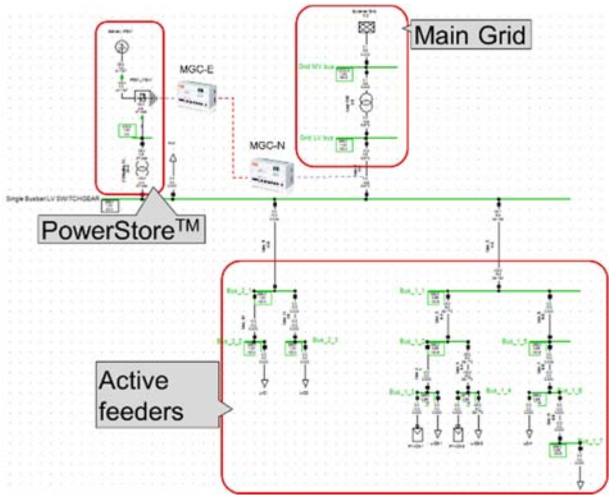

Figure 1 - Torsebo Microgrid layout

The main control functions required to the system are listed in Table 1.

Table 1 - Torsebo Microgrid functions

Function	On-grid	Off-grid
Voltage / Reactive power control	✓	✓
Peak shaving	✓	
State of Charge (SoC) management	✓	✓
Power balance and frequency control		✓
Black start		✓
Planned islanding	✓	
Unplanned islanding	✓	
Automatic resynchronization		✓

MICROGRID SOLUTION

ABB Microgrid Plus System

The ABB Microgrid Plus control system has a decentralized architecture in which each asset has a controller providing commands to the assets and all controllers communicate with each other. Detailed discussion of the control architecture and philosophy is beyond the scope of this paper. For further insight into this topic refer to [3].

For the Vattenfall project two Microgrid Plus Controllers (MGC) will be installed, one for the network interconnection (MGC-N) and one for the energy storage (MGC-E).

ABB PowerStore^{TM}

The ABB PowerStore^{TM} is an energy storage solution specifically developed for for microgrid applications [4]. It can be classified as a grid forming inverter with an outer Virtual Generator (VGM) layer. This fully emulates a synchronous generator since it features the exciter and the governor control blocks, including inertia.

It can be operated both on-grid and off-grid and allows the seamless transition from one operating scenario to the other.

Challenges

Developing a robust and efficient automation and control solution poses many challenges. One of the most significant is the implementation of the design concept on the target hardware controllers. A manual code implementation is error prone and translates into a more time consuming and less efficient development process which requires additional testing. Ultimately a manual approach slows down system testing and commissioning. ABB applies a state of the art model driven code generation workflow, depicted in Figure 2. The control logics are developed and unit tested in the Matlab-Simulink [5] environment, then the code for the target hardware is automatically generated and deployed.

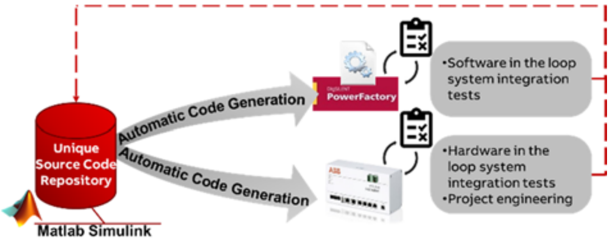

Figure 2 - Development workflow

TEST SETUP

To further speed up and reduce the costs of the system testing, a HIL set up, illustrated in Figure 3, is utilized. Real hardware controllers are connected with DIgSILENT PowerFactory [6], a power system simulator, to test the control and automation solution in a variety of scenarios achieving good fidelity and high coverage without being constrained by the costs and additional overhead related to interfacing with real power devices. HIL test set up benefits are well understood in the industry and several references can be found in the literature [7], [8].

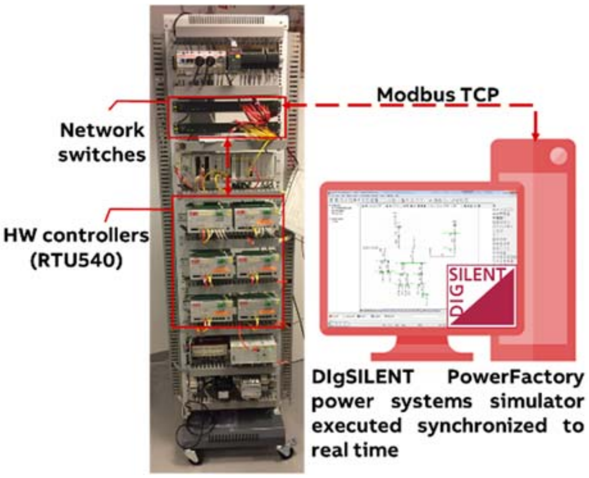

Figure 3- HIL simulation set-up

The utilized set-up, running on a Windows machine, is not a proper deterministic real time system. However, for this kind of secondary level control functions, PowerFactory running synchronized to system time is enough to provide a meaningful feedback to the hardware controllers.

Primary control logics like the PowerStore^{TM} Virtual Generator and electrical equipment like meters, protections and inverters are modelled in a detailed way within the PowerFactory environment.

The set-up allows to engineer the logics on the hardware controllers, configure both the vertical (to and from the field devices) and the horizontal (to and from the other Microgrid Plus Controllers) communication using industrial tools and protocols.

USE CASES

Grid Connected Operation

While on grid the mission of the system is to support the voltage and improve the load power quality. The Microgrid Plus system can control the PowerStore^{TM} to regulate the voltage where there are available measurements: at his own bus or at the network interconnection bus. Instead of voltage control, it is also possible to activate power factor compensation at the network interconnection to maintain the power factor at the desired value.

The PowerStore^{TM} also allows to shave the power peaks at the network interconnection. Performances are going to be affected by the available capability (in this project The PowerStore^{TM} will be operated in Q priority mode), the peak shaving settings, the duration of the peaks and the battery State of Charge (SoC). Peak shaving thresholds and SoC management can be configured according to parameters which will be tuned during commissioning and then refined during operation.

For testing purposes, in order to limit the simulation duration to a few minutes, feeder load and PV generation profiles have been defined so that the system could experience peak power flows in both import and export.

The peak shaving limits have been set symmetrically to +/- 15 kW.

To summarize, in this case the active functions are:

- Peak shaving
- Auto recharge
- Voltage control

External active and reactive power setpoints could also be enabled for the BESS but they would override all other functions. Simulation results are depicted in Figure 4, Figure 6 and Figure 5.

It is possible to notice how the PowerStore™ supports the voltage and maintains the power flow at the network interconnection within the peak shaving limits.

Because the simulation duration is limited the PowerStore™ SoC only slightly changes. When the network power flow is within the peak shaving limits the auto recharge algorithm is active but the recharge power setpoint is in this case limited because the SoC is already close to the ideal SoC, set to 50%.

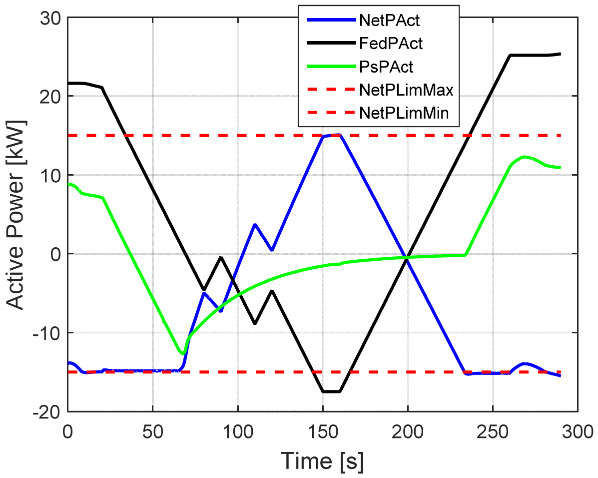

Figure 4 – Network power (blue solid line, positive if grid export),feeder power (black solid line, positive if consumed power), PowerStore™ power (green solid line, positive if discharging), peak shaving limits (red dashed lines).

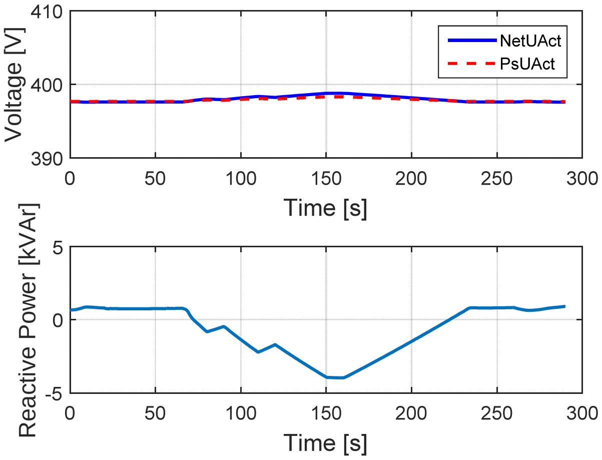

Figure 5 – top plot: network and PowerStore™ bus voltages (blue solid and red dashed lines respectively); bottom plot PowerStore™ reactive power.

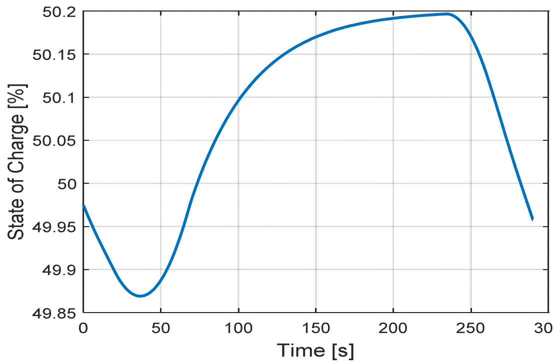

Figure 6 – PowerStore™ SoC

Unplanned Islanding

When operating off-grid the mission of the system is to form the grid and control frequency and voltage. In this scenario the network breaker is switched open at 15 seconds, power on the MV grid is lost and the system operator runs the LV microgrid in island mode. The simulated feeder power profile is the same of the previous scenario.

Simulation results are depicted in Figure 7, Figure 8, Figure 9 and Figure 10.

The network breaker trips, the PowerStore™ balances the load and the virtual generator logic produces a frequency transient as if there was a traditional generator. As soon as the MGC-E receives the information from the MGC-N that the system is now off-grid the peak shaving automatically disables while the frequency control enables. System frequency and voltage are regulated within a configurable dead band centered on the nominal value compensating the droop offsets as the Microgrid load changes.

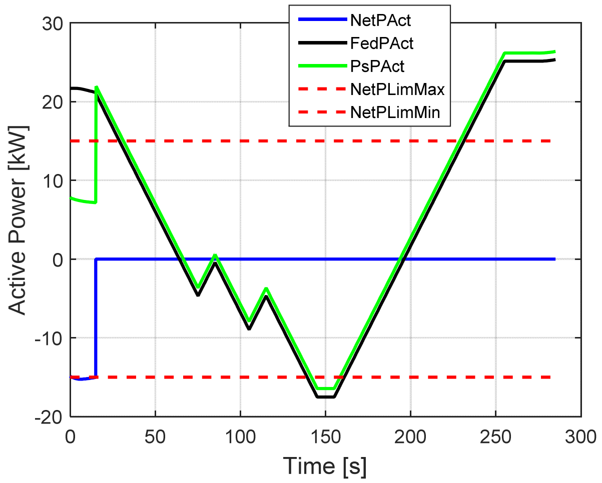

Figure 7 – Network power (blue solid line, positive if grid export),feeder power (black solid line, positive if consumed power), PowerStore™ power (green solid line, positive if discharging), peak shaving limits (red dashed lines).

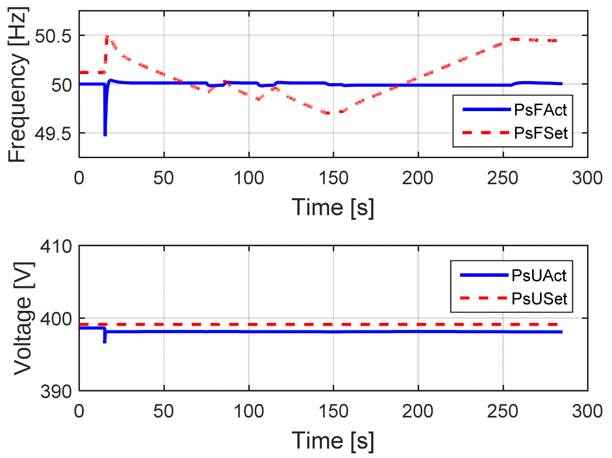

Figure 8 – Overview. Top plot: PowerStore^{TM} frequency measurement and frequency setpoint (blue solid and red dashed lines respectively); bottom plot PowerStore^{TM} voltage measurement and voltage setpoint (blue solid and red dashed lines respectively).

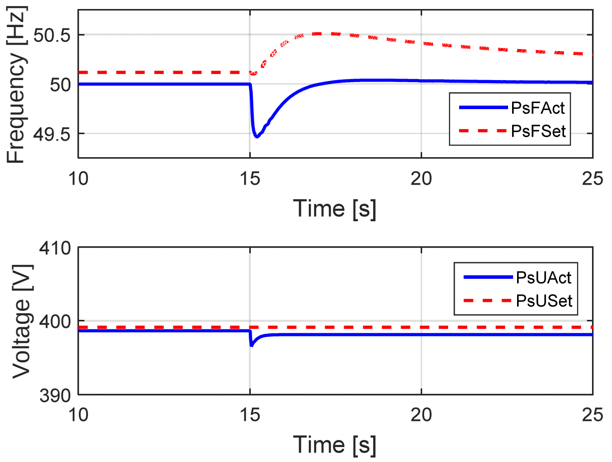

Figure 9 – Detail. Top plot: PowerStore^{TM} frequency measurement and frequency setpoint (blue solid and red dashed lines respectively); bottom plot PowerStore^{TM} voltage measurement and voltage setpoint (blue solid and red dashed lines respectively).

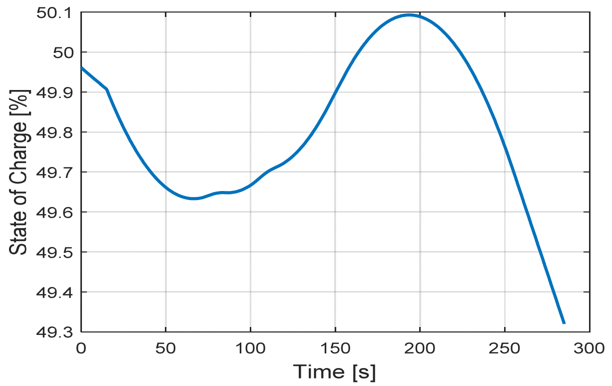

Figure 10 – PowerStore^{TM} SoC

CONCLUSIONS

This paper demonstrates how a decentralized Microgrid control system, implemented and engineered on real hardware devices, can be tested with good coverage and fidelity interfaced to a low cost power systems simulator. On the application side it has been shown that currently available state of the art technology enables to deliver a variety of support functions for distribution systems including surviving an unplanned islanding event and running the islanded system controlling voltage and frequency.

Even though of limited power and energy ratings the Torsebo project is extremely interesting and important as it will allow to assess the benefits of energy storage systems connected to present and future European distribution systems.

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