GROW-DERS: GRID RELIABILITY AND OPERABILITY WITH DISTRIBUTED GENERATION USING FLEXIBLE STORAGE

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ABSTRACT

The GROW-DERS project (Grid Reliability and Operability with Distributed Generation using Flexible Storage), funded by the European Commission, aims to solve the technical challenges associated with distributed energy resources by using transportable and flexible storage systems.

This paper discusses how recent developments in Li-ion batteries, flywheels and power electronics can be applied to use electricity storage systems in such a way that they manage the energy grid. These technologies are used in a number of demonstration test sites across Europe. In the demonstration test sites the technical feasibility is proven. The project also examines a technical-economic software assessment tool that is being developed to optimise the location, type and size of storage systems for distribution grid applications.

INTRODUCTION

Distributed Energy Resources (DER), such as photovoltaic's and wind turbines, are increasingly being added to European distribution networks to reduce CO_2 emissions and to improve energy efficiency. The challenges introduced by DER on Low Voltage (LV) networks include potential overloading of network components, over/under voltage situations and power quality problems.

Recent developments in power electronics potentially enable storage systems to be transportable (containerised) and flexible so that they can be deployed by Grid Operators on distribution networks to alleviate the problems introduced by DER [1].

The GROW-DERS project aims to demonstrate the technical and economical maturity of transportable and flexible grid connected storage systems. It includes the development and testing of storage systems, as well as the development of an assessment tool to determine the optimal location, size and type of storage systems to be used.

The GROW-DERS project is funded by the European Commission (FP6). Project partners represent the entire electricity value chain and include KEMA, Liander, Iberdrola, MVV, EAC, SAFT, EXENDIS, CEA-INES and IPE.

TECHNOLOGY DEVELOPMENT

A review of existing storage technologies found that Lithium-ion (Li-ion) battery and flywheel systems are currently two of the most suitable and promising storage systems that can be containerised and transported to different network locations as required. Following the requirements definition, specifications for the following components of the storage system were developed, followed by the design and construction thereof.

Li-Ion Battery System

For the project SAFT (France) developed a Li-ion battery unit consisting of 2 cabinets that contain the batteries, circuit breaker and Battery Management Module (BMM). The 400V battery system was designed for a low power rating (10kW), but a high energy output (40kWh) to support the project objectives. Maximum charge current is 50A and maximum continuous discharge current is 200A.

The separate Energy Storage Inverter (ESI) monitors and manages the charging and discharging of the battery via a CAN bus communication system in accordance with the cell voltages and temperature to optimise battery performance and life. The battery's safety functions are managed by an internal module.

Flywheel System

Flywheels are typically used for short discharge applications where high power is required for example to ride through voltage dips. Compared to battery systems the energy output is usually considerably lower. A 160kW flywheel was selected to demonstrate voltage improvement capabilities during network disturbances. The flywheel is a single self-contained cabinet that can supply 0.9kWh of DC energy during supply interruptions.

Energy Storage Inverter (ESI)

A portable ESI was developed by EXENDIS (Netherlands) for the project. The inverter is a 60kW bi-directional galvanic isolated power converter that supports an input of 329-450 VDC and an output of 3 x 400V AC. Additional functions that were specifically developed for GROW-DERS include a UPS (islanding) mode, reactive power compensation, dip and flicker compensation and active harmonic damping. The ESI was developed to be remotely controlled by higher level management systems using the ModBus protocol.

Energy Management System (EMS)

Management and co-ordination of the storage system components are performed by a remotely located Energy

Management System (EMS) developed by CEA-INES (France). The EMS receives selected measurements from the battery, flywheel, and ESI, and uses these to calculate optimal charge and discharge set points in accordance with pre-defined objectives and constraints. Communication of the measurements and set points between the EMS and ESI takes place via GPRS as illustrated in Figure 1.

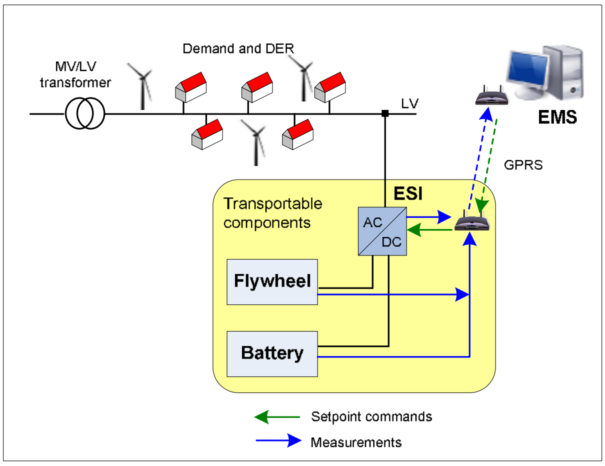

Figure 1: Flexible Storage System configuration

The EMS utilises three levels of management to manage the storage system:

- A planning level which uses forecasted electricity prices for the day ahead to determine the optimal set points to maximise the profit objective though energy trading.
- A real-time management level which uses real-time measurements to calculate instructions to be sent to the ESI so that stored energy can be used to alleviate overload, over/under voltage, and power quality constraints.
- A real-time control level which focuses on optimising component life and equipment safety.

Developments are currently underway to expand the functionality of the EMS to include the management of multiple storage systems on the same distribution grid.

LABORATORY AND FIELD TESTS

Laboratory tests were performed in the Netherlands and France to validate the functioning of the flywheel and batteries respectively, and to verify correct integration of the EMS and ESI components.

Laboratory testing

The laboratory testing enabled the simulation of a wide variety of network conditions with varying degree of intensity to validate the behaviour of the EMS, the ESI, batteries and flywheel. Tests included active and reactive power scenarios, voltage dips, over and under voltage conditions, harmonics and islanding.

The hardware successfully passed all the tests, and the results were used to enhance the software of the ESI to provide improved compensation for power quality phenomena such as voltage dips and flicker.

Field Tests

Four field test sites were selected to validate the transportability, installation and operation of the storage systems:

- Zamudio (Spain) – battery system 1
- Chambery (France) – battery system 2
- Zutphen (Netherlands) – flywheel
- Mannheim (Germany) – combination

Field tests are currently being performed at the first three demonstration sites. Once the first three field tests have been completed all the devices will be transported and installed at the test site in Mannheim to demonstrate the combination of the different storage technologies and the management of multiple storage systems.

Provisional analysis of the acquired measurements from the test sites indicate that the storage system is operating correctly and that it is technically feasible. Further analysis is however required in order to exactly quantify the voltage and power quality improvements achieved by each storage system. The analyses will be performed in the coming months together with an economic assessment of the systems.

Learning points from the field tests so far include:

- The storage system components can be easily containerised and transported to site. Installation requirements are minimal.
- Li-ion batteries have specific handling, storage and transportation requirements. The batteries are classified as dangerous good class 9; obtaining permission from the relevant transportation authorities to transport the Li-ion batteries proved harder than anticipated.
- Reliable communications between the EMS and the rest of the system components is essential for the correct functioning of the storage system.

STORAGE PLANNING TOOL (PLATOS)

As part of the GROW-DERS project KEMA (Netherlands) has developed a software tool called the PLAnning Tool for Optimised Storage (PLATOS) to optimise the application of storage systems. This tool is able to optimise the location, size and type of storage systems for any distribution grid.

Functional Description

PLATOS has been developed using the scripting language of DIGSilent PowerFactory. It utilises a model of the electrical network and the power flow analysis functionality of PowerFactory. The tool consists of the following modules as depicted in Figure 2 below:

- Solution generator
- Alleviation algorithms (3)
- Trading algorithm
- Input data processing
- Output data processing
- Solution assessment

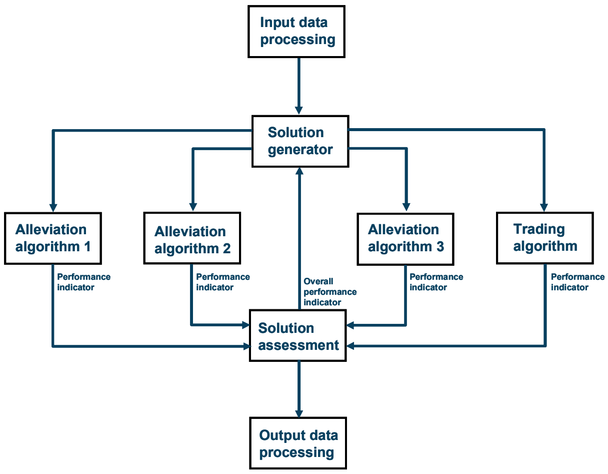

Figure 2: Functional overview of PLATOS

Solution Generator

The Solution Generator forms the core of PLATOS. Its function is to generate large numbers of unique storage solutions to achieve user defined objectives and to alleviate the technical constraints of the electrical grid. Each solution represents a specific combination of storage locations, storage sizes and storage types. The optimisation of the location, types and sizes of storage devices in a power system is essentially a combinatorial problem that can have many different solutions. Although such a problem can be solved by means of brute computational power, PLATOS follows a more efficient approach by using Artificial Evolution (AE) principles.

AE is a computational technique that involves a number of individual evolutionary algorithms. In the case of PLATOS the genetic algorithm was selected as the most suitable. In principle the algorithm generates a number of random storage solutions, which are then analysed and evaluated. The best solutions are selected and then used as the basis to create even better solutions. The process is repeated until the optimum storage solutions are found.

Alleviation Algorithms

Storage systems are typically applied in distribution grids to alleviate technical problems, especially where DER is concerned. These technical constraints include, inter alia:

- Voltages exceeding lower or upper limits
- Currents exceeding upper limits, i.e. overloading
- Voltage dips

The alleviation algorithms in PLATOS assess the ability of the storage solutions proposed by the Solution Generator to alleviate each of the different technical constraints that exist for the particular distribution grid. The result of each assessment is quantified as a performance indicator.

Trading Algorithm

Besides the alleviation of technical constraints storage systems can also be utilised for energy trading purposes. The trading algorithm assesses the cost and benefits of using the proposed storage system for trading activities. The result of this assessment yields the trading performance indicator.

Input Data Processing

For the correct operation of PLATOS, the user has to enter certain input data. The input data includes:

- The number of solution spaces e.g. the number of storage devices available.
- The specifications of available storage devices (e.g. size, charge/discharge rate etc.)
- Short term forecasts of generation and load
- Parameters to be used in the solution assessment e.g. equipment costs.
- The simulation period

Output Data Processing

For each solution PLATOS generates the following output data:

- Optimal location, size and type of storage devices
- Active and reactive power setpoints for each storage device
- State of charge of each individual storage device
- Performance indicators based on assessment criteria

Solution Assessment

A solution assessment is performed for each storage solution proposed by the Solution Generator. This is done by calculating the individual performance indicators for each alleviation algorithm as well as the trading algorithm, and then combining the result in an overall performance indicator.

The performance indicator for each algorithm is calculated as the economic benefit (i.e. benefits minus costs) provided by the particular storage solution. Costs include both fixed and variable costs. Fixed costs relate to the initial capital investment of the storage system, while the variable costs relate to the number of charging and discharging cycles, energy losses, life time reduction of the storage systems etc. Financial benefits include investment deferral options as well as investment avoidance of solutions that would have been otherwise required to alleviate the network constraints.

The solution with the highest overall performance indicator is considered to be the optimal storage solution and the one that is recommended for the distribution grid.

Preliminary results

PLATOS has been developed in parallel with the EMS, ESI, batteries and flywheel, and to date has been used to simulate two of the four test sites. Different sets of input data e.g. different storage solutions and different generation and load profiles have been used to validate the optimal storage solution proposed for each specific situation. An example of the results is shown in Figure 3.

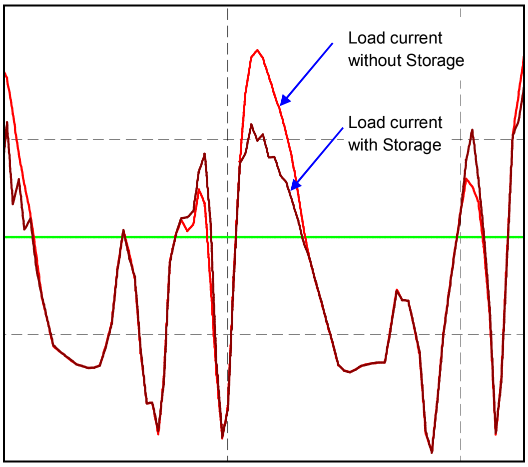

Figure 3: Example of storage simulation

The simulations confirm the results from the laboratory tests, namely that, transportable storage devices, such as Li-ion batteries and flywheels are technically feasible on a distribution grid to alleviate the technical constraints such as overloading, over/under voltage and voltage dips while at the same time exploiting potential trading opportunities.

An immediate next step in the development of PLATOS is to use actual costs and measurements from all four the demonstration sites to validate the technical and economic solutions proposed by PLATOS.

CONCLUSION

The GROW-DERS project has designed and developed transportable and flexible storage systems that can be used to improve the management of distribution grids, especially when DER is used. In addition an innovative storage planning and assessment tool (PLATOS) is being developed that can assist network planners to determine the optimal size, type and location of storage systems to be implemented. This will result in the best technical and economical application of storage systems on distribution grids.

Simulation results have shown that transportable and flexible storage systems are technically feasible with respect to alleviating distribution grid constraints. During 2010 actual measurements from all four demonstration sites will be used to quantify the technical and economical benefits of transportable storage systems. The findings will be used to provide concept directions for the EU regulatory framework in terms of interconnection standards and cost allocations with respect to flexible and transportable storage systems.

REFERENCES

[1] X. Le Pivert, Y. Riffoneau, P. de Boer et al, 2009, "*Report on applications for storage in distribution networks*", available at www.growders.eu.