INVERTER TO GRID: VOLTAGE CONTROL STRATEGIES FOR GRID INTEGRATION OF DISTRIBUTED ENERGY RESOURCES

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ABSTRACT

In the context of renewable energy integration into the distribution grid, this paper ~~proposes~~ introduces the concept of synchronized control of many inverters distributed on a low voltage network. Compared to the standard Volt-VAr control, the synchronized control presents substantial advantages. It can better control voltage on a line and add further services such as reactive power compensation at the district level for minimization of losses.

In future microgrids with a generalized communication between components, the synchronized control is possible and is really a feature to consider.

The concepts developed during this project have been simulated but also implemented on industrial components in the new GridLab laboratory at the University of applied science of western Switzerland HES-SO Valais.

INTRODUCTION

Renewable energy integration into the grid is a reality in today's energy system. Dozens of Gigawatts of new photovoltaic are installed every year in the world.

Most of the new renewable energy is produced by small to medium-sized distributed power plants directly connected to the distribution grid. Despite the addition of local storage in some cases, production mostly depends on weather conditions and remains barely controllable and predictable. As the fraction of renewable electrical energy supplied to the grid is growing, new control strategies are needed for the distribution grid management. Accurate monitoring and real time control of sources, loads and storage system in the distribution grid took the common name of "Smart Grid"

Active in-feed converters connected either to a production plant or to energy storage devices will take a key role in the new control strategies. Intelligence supported by powerful micro-controllers associated to Power electronics devices and communication system will boost the efficiency, the controllability and the reliability of local electrical distribution grids. The main objective of the « Inverter Integration into the Grid » I2G project was to conceive new converters structures and features in order to support power availability, quality and efficiency of the grid at reduced costs. Not only new power electronics components, but up-to-date controllers and communication tools were integrated into the developed 'intelligent converters' architectures. In order to synchronize their actions, so called Intelligent Electric Devices (IED) need to share information with the other actors of the electrical distribution system. Systemic aspects of information and communication technology were addressed during the project: 'what information has to be shared for what purpose?' as well as technological aspects: 'how to communicate, relying on which protocols?' New control strategies linked with ICT as well as their implementation and evaluation in an innovative testing infrastructure are presented in this paper.

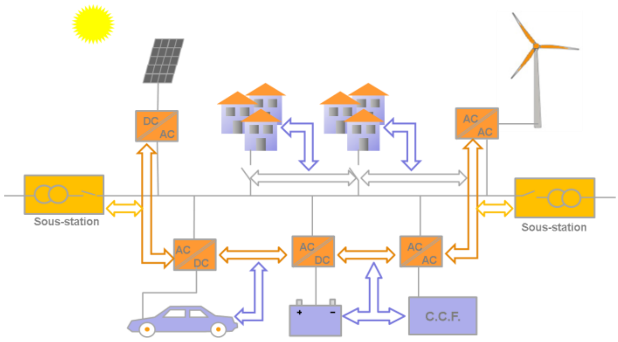

Figure 1 *Smart distribution system.*
Narrow lines: power lines ; wide arrows: ICT

THE CONCEPT OF SYNCHRONIZED CONTROL

The SmartGrid, incorporating active elements able to communicate, is a future vision for grid control. Today we are defining this future that will create a more flexible grid for controlling energy production and consumption.
As a hot topic, general studies about this subject were done in almost all major research institutes. The Phd thesis of Martin Braun from ISET [1] presents a good overview of the Ancillary Services that distributed generation can perform on grids, including economical aspects. [5] and [6] are shorter papers on this subject. More specific to the control of converters treated in this paper, the work of DERlab [2] is a reference.

Many technical evolutions have already been done in the recent past. For stability of voltage control and to integrate even more distributed renewable energy in the grid, possible control of reactive power has become mandatory in several countries, especially in Germany with the VDE-AR-N-1405 rules.
In Germany mid-size inverters must have a simplified control of active power and leave the possibility to modify power factor manually to the distribution system operator (DSO). This could be automated soon.

Modern photovoltaic inverters have communication capability for monitoring solar production. The same communication link could be used for control.
The local setting of a solar inverter is done with a fixed power factor or a more dynamic control: a Volt-VAr curve that modifies the power factor as a function of the measured local voltage.
A supervisory unit that communicates with all the inverters in a given subnet/microgrid has a precise global view of what's happening. It can therefore control all the inverters of the microgrid to optimize the global behavior. Implementing this is the next step in distribution grid control, now that the inverters are able to perform local control.
[3] introduces the idea of a centralized control that has better performances than local regulation loop alone. Inverters at the end of the line are less stressed and reactive power is globally lower. Similarly [4] proposes a centralized control to minimize reactive power on the grid.
In the 'Inverter Integration to the grid' project we implemented this kind of centralized control that allows synchronizing the behavior of all the inverters distributed over a network.

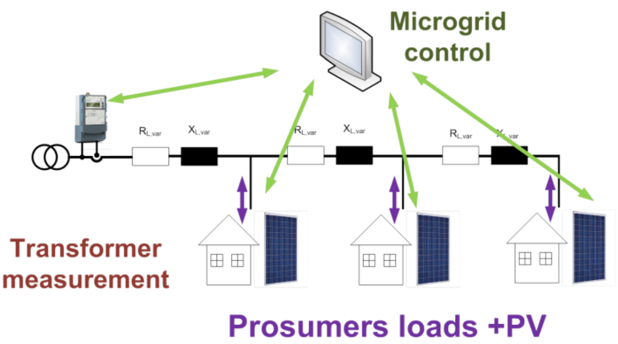

Figure 2 *The global view of the microgrid allows controlling it for a global optimum.*

SIMULATION OF A MODEL PREDICTIVE CONTROL (MPC)

A first control method based on Model Predictive Control (MPC) was developed. MPC is a natural candidate for a control with a global optimal target taking into account various goals. The principle is to create a model of the micro-grid (process to optimize). This model can be simulated and many possible set points are tested in simulation. The best one is kept.

The optimization goal is the minimization of a cost function. It is defined as the cost on the grid:

- Cost/kWh for losses.
- Cost/kVAr for reactive exchanged with the grid.
- Penality costs for voltages out of tolerances.

This cost function is optimized by an algorithm. In this first phase we used the standard constrained minimization function of MATLAB.

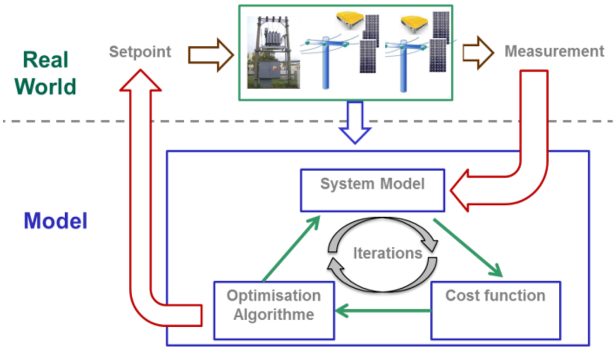

Figure 3 *Model Predictive Control (MPC)*

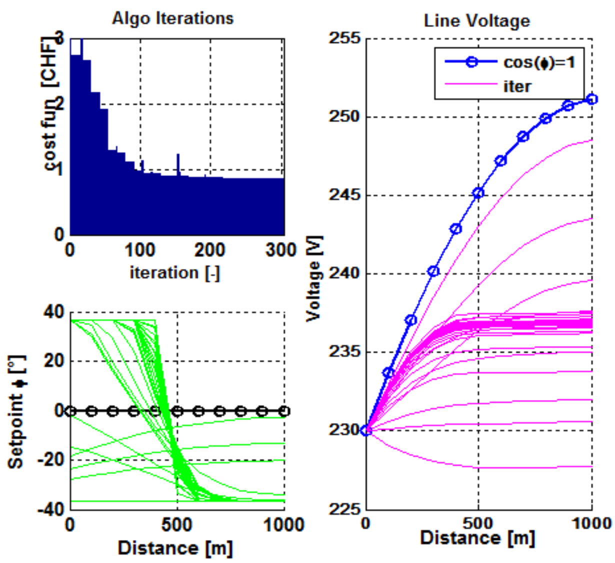

Figure 4 *Iteration of optimization algorithm and convergence to the best way to control the microgrid*

In the end the algorithm finds the cheapest way to operate the microgrid by minimizing cost (the cost function). Different penalties are used as a function of voltage. With high voltage there are high penalties and this becomes predominant over losses and reactive power minimization. With a careful selection of costs and penalties in the cost function, the results are very satisfying.

Figure 5 below shows the simulation results for a weak aerial line of 1km with a producer every 100m on the line. This is a theoretical reference case. We see on this picture the behaviour of the control: the inverters at the beginning of the line are close to the transformer and have little influence on the voltage at the end. Those are asked to produce capacitive reactive power that raise the voltage faster, but compensate the inductive reactive power at the end of the line.

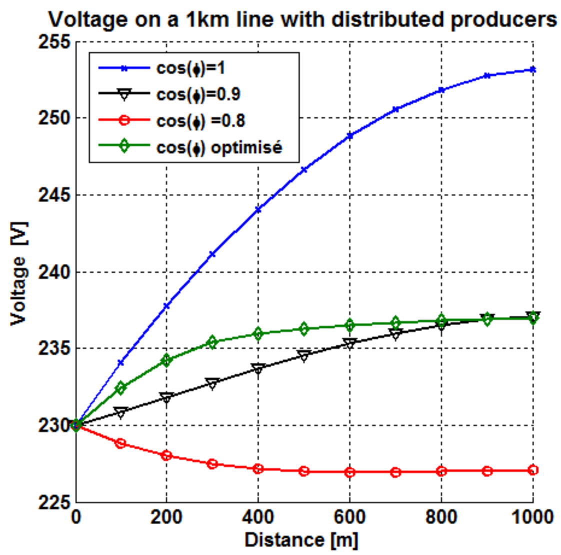

Figure 5 *Simulation results of MPC control: synchronized control allows maintaining voltage and minimizing reactive current at the same time.*

A SIMPLIFIED CONTROL VERSION

The MPC concept is promising but in a short to mid-term vision we think it is probably too complicated to be generalized in the distribution grid. Setting up a model is a time consuming engineering task and knowledge of the distribution grid parameters is sometimes incomplete. With this in mind we decided to develop a simplified version of the control, without exact modeling and no heuristic. Our goal is to be able to implement it very easily and quickly on any new implementation. The grid topology is not modeled precisely, because the only basic information absolutely necessary for our purpose are the positions of the inverters relatively to the transformer (toward the beginning of the line or close to the end). The control is similar to a classical Proportional-Integral (PI) control. One PI is used for every converter, but the input (error) is influenced by the state of the whole microgrid and the position in the grid.
The results are quite similar to the MPC control. This second method was implemented on the real devices of the Gridlab.

IMPLEMENTATION IN THE GRIDLAB

Direct implementation of new control algorithms on a real distribution grid represents too high a risk for grid components and connected loads. The Synchronized Control concept was first tested and evaluated at the GridLab laboratory at HES-SO Valais in Sion.

The GridLab Low Voltage is a full scale experimentation platform dedicated to research and teaching activities in the field of renewable energy sources and storage integration into the grid. A three phase 400Vac feeder to which loads and sources are connected is at the heart of the GridLab District. For better efficiency and increased flexibility, consumer's loads, production plants and storage systems are emulated with the help of static converters. A state-of-the-art communication system allows data exchange between converters and a centralized control unit. Real loads, storage units and a photovoltaic production plant complete the GridLab District for components testing and evaluation

Figure 6 *View of the GridLab facilities at HES-SO Valais.*

Within the GridLab District, energy transfers with the emulated low voltage feeder are very efficiently controlled through bi-directional static converters. For reasons of economy and in order to provide a more realistic environment, the platform consists of market-available industrial components. The 3 x 15 kW units equipped with industrial Active Front End were developed at ABB Drives. Up to twelve 15kW AC/AC converters can be parallel connected on one side to the GridLab Feeder and on the other to an independent section of the 400VAC Grid. This solution allows a reduced overall energy consumption of the laboratory, while providing greater flexibility of use. Each component at the GridLab is equipped with Ethernet connection allowing individual distance control and electrical values monitoring. The IEC 61850-90-7 standardized communication protocol is applied whenever possible.

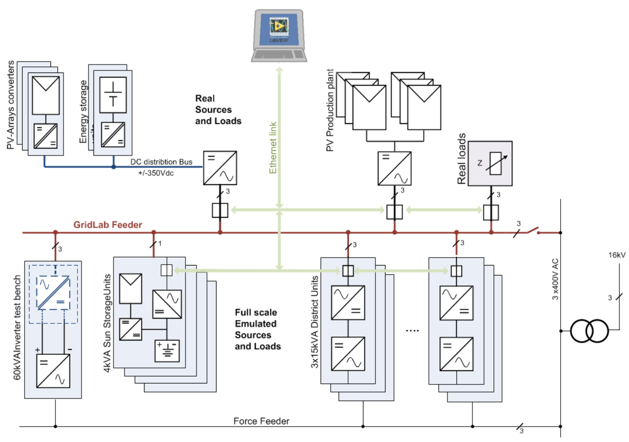

Figure 7 *The GridLab infrastructure.*

Line feeders characteristics have a critical impact on voltage instabilities due to distributed production in a local distribution grid. In the GridLab Street Unit, lines connecting the bi-directional 15kW programmable converters are emulated with discrete resistive and inductive components developed for this specific application. Distributed line resistances and inductances corresponding to a 500m typical 4xAL195mm2 ground cable, respectively a 500m typical NAVY-J 4x95 aerial connection are realized. Those can be selected in accordance to the grid topology we want to reproduce.

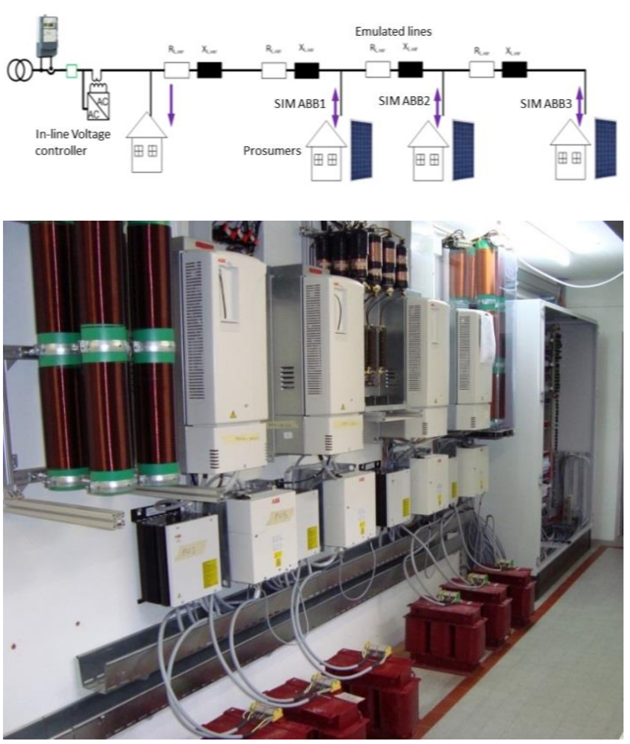

Figure 8 *Principle scheme and view of components used to emulate prosumers and feeders in the Gridlab units.*

PV PRODUCTION AND SYNCHRONISED CONTROL SCENARIOS

Scenarios with daily photovoltaic production were realized on a GridLab Street Unit set-up, three 15kW inverters emulating PV plants connected along a 1.5 km low voltage feeder. The algorithms were controlling the active and reactive power delivered to the line by each converter. The Street unit set-up is represented on Fig. 2. Resulting voltage along the line is displayed on Fig. 9. It can be seen on the right side of the figure that the 'synchronized Volt-VAR control' algorithm was able to maintain the line voltage at the point of common coupling of the prosumers with the feeder within the maximal +4% variation which is specified in the DACH-CZ Technical rules for the assessment of network disturbances.

For the scenarios, line voltage at point of common coupling was measured by smart power meters. IEC 61850-90-7 standardized communication protocol was used in order to transmit voltage values as well as active power and reactive power references to the converters.

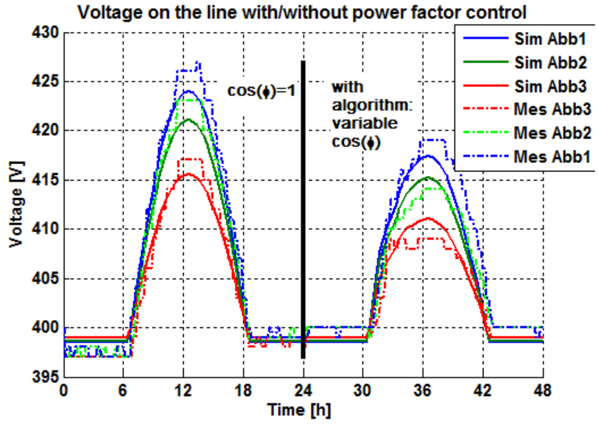

Figure 9 *Tests results (MES) compared with Simulation (SIM) for two days with and without the control algorithm.*

CONCLUSION

At first it looked like that distributed energy generation and storage would present a risk for the power quality on distribution grid. It is shown in this paper that intelligence and communicating capability added to Active In feed converter could reduce risk and even represent an advantage for the grid operability. An optimal synchronized algorithm controlling the reactive power delivered by inverters connected to a low voltage feeder made it possible to keep the feeder voltage within acceptable limits and at the same time reduced the total reactive power consumed by the whole street feeder.

Communication links are already implemented in modern PV inverters. Control algorithm implemented at the dispatching level would represent a smart alternative to costly grid lines reinforcement.

MISCELLANEOUS

Acknowledgments

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