PILOT SYSTEM “INTELLIGENT LOW VOLTAGE GRID”

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ABSTRACT

In the context of numerous demonstration activities and pilot deployments of Smart Grid technologies in Austria, the need for a testing environment for automation components, smart grid controllers and their parameterization became obvious. This paper describes the design and functionality of the pilot system “Intelligent Low Voltage Grid”, which has been developed for this purpose in the context of the close cooperation between Siemens Austria and the Institute of Computer Technology at Vienna University of Technology.

INTRODUCTION

One of the main topics for grid operators in Austria is, like in many other countries, the grid integration of renewable energies in the medium and low voltage level. The activities around the project chain “DG DemoNet” since 2006 [1] and the Smart Grids Model Region Salzburg [2], where universities, research institutions, distribution grid operators and industry work together successfully, deal with this challenge. Also similar projects with European network operators (see eg. OpenNode project [3]), have led to a set of innovative and powerful control solutions for active operation of low voltage networks. Especially to solve the voltage problems in rural networks with long lines and a high penetration of photovoltaic (PV) installations, dedicated voltage control approaches have been developed and are in the process to be demonstrated in multiple real low voltage grid segments over Austria [4]. The essence of these control concepts for the low voltage is that measurement data is taken from smart meters in the field, processed by a controller associated to the medium voltage-low voltage (MV-LV)-substation and actions for an MV-LV tap changer are issued. Further, real-time adaptations of the reactive power management of PV inverters in the grid are performed if necessary. Charging stations for electric mobility can also be included in the scheme.

SYSTEM DESIGN

The pilot system “Intelligent Low Voltage Grid” is designed to be a dedicated testing and presentation environment for real-world control and automation components that will be part of the above mentioned field tests.

Grid Concept

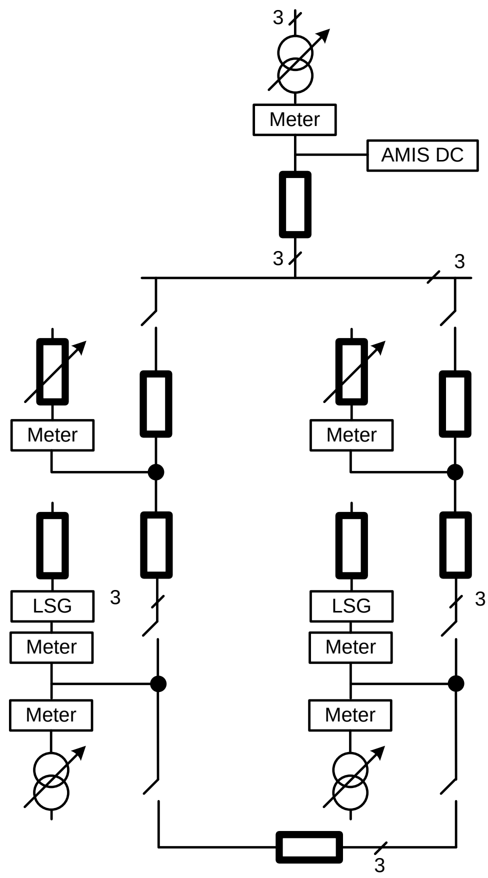

Figure 1 - Abstracted view on the wiring of the pilot system

The pilot system itself consists of three cabinets, the transformer cabinet and two line-cabinets, representing two different buildings. One of the buildings represents a 3-phased consumer and the other building consists of a one phased producer (PV generation) and a one phased static load – switchable by a power line device (Siemens LSG). In order to demonstrate a variety of grid topologies, circuit switches are located between each of the cabinets and the components. All voltages are in the same range as in a real LV grid. In order to generate a recognizable voltage drop/increase by loads/PV feeds the line impedances and thus also the currents are scaled by a factor of approximately 100 as compared to a real LV cable grid. An already planed enhancement is the integration of additional impedances to enable further investigations dealing with the specific behavior of overhead distribution lines. The MV-LV transformer is represented by three adjustable single phase insulating transformers. Also PV generation is simulated, resulting in a voltage increase by feeding current to the grid. Three time-variable current sinks characterizing the building by draining current. All components can be configured by the automation system in real time.

Figure 2 - Pilot System

Automation Concept

Emulation of Consumers, Producers and the MV-Grid

Each dynamic consumer is emulated by three current sinks that are controlled by a computer via USB. Each one can consume up to 500 mA. By application of the above mentioned approximated factor of 70-100 this results in a load that is equivalent to real world residential loads. The two static loads that are connected to the same feed as the PV are static resistors. Remote controlled switches from the used smart metering product system are turning the two static consumers on/off. The phase for the static load can be manually selected.

Similarly the photovoltaic infeed is emulated by a one-phased insulating transformer controlled by the same computer. The maximum current that can be used is around 3.2 A. Thus, a scaled peak performance of a PV on the roof of a family home with 5 kW can be easily emulated. Due to the fact that the power flow is not restricted to one direction by application of diodes, the control system has to keep the voltage level of this transformer higher than the connected grid voltage level. Otherwise the emulated photovoltaic would act as a current sink. Again, the phase for the photovoltaic can be manually selected. Currently, the modeled PV installation is not capable of power factor adjustments; only active power reduction of PV generation can be simulated. This limitation enables a considerable simplification in the design.

The same transformer is used for the emulation of the secondary substation. For each phase one transformer controls the voltage level with an integrated controller that gets its set point via USB. Depending on the amount of energy consumed by the current sinks and the energy provided by the photovoltaic systems the power flow can be down- or upstream. In case of upstream – the low voltage grid produces more energy than consumed and feeds it back into the medium voltage grid – the in-built transformer controller has to be turned off. Otherwise the set point values of the controllers of the substation transformer and its corresponding photovoltaic transformer would start to oscillate. The result would be a non-desired behavior of the low voltage grid and potential damage to the transformers.

The components can be operated in two time modes: real-time and fast motion. The maximum speed is up 720 times faster than real-time (24 hours in 2 minutes). The exceptions to this are the two static loads. Smart metering appliances are designed to operate in rough environments and they are using power line communication. Thus, turning a static load on/off can take up to several seconds. This has to be considered while defining a simulation setup and its specified time responses.

Smart Meter Infrastructure

The integrated smart meters are part of the AMIS Smart Grid Metering infrastructure from Siemens. The meters are used to measure voltage, active and reactive power and the phase angle. Data is transmitted via power line communication to the data concentrator – AMIS DC. From there the information is forwarded for further processing using Ethernet and the IEC 60870-5-104 protocol.

The remote switch is the AMIS LSG that is connected similarly to the meters to the AMIS DC via power line communication.

Head end systems that receive data from the DC are the meter data management represented by the AMIS-TS (transaction server), a control center (Sicam230), and an industrial PC that can operate as an intelligent secondary substation node. All three systems can send commands back to the DC.

Of course, any other metering system (or a mixture of different ones) can be used. The important point is that realistic communication system setups should be taken.

Data processing

To decouple data acquisition and command forwarding from simulation implementation an event driven data point server is used. Clients can register to various data points. In case a client writes to the server an update of the new value is broadcasted to all relevant clients.

Currently, two system clients exist: a USB-device client and the tap changer client. The first one maps the connected transformers and sinks to predefined addresses. The later one calculates the set values for the three secondary substation transformers. Such, a tap changer transformer can be emulated. Next to the system clients, the simulations are clients connected to the data point server. The one currently implemented is done with LabView and introduced in detail below.

Communication Overview

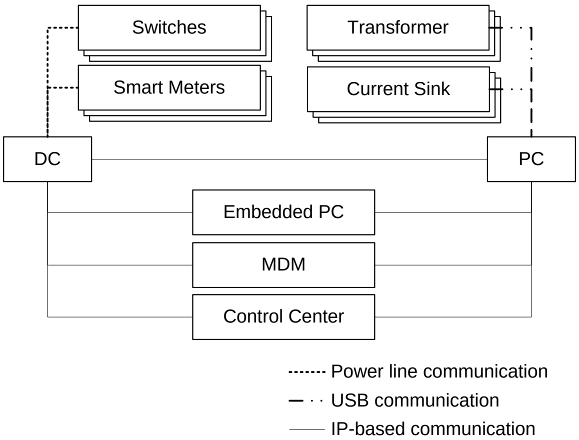

Figure 3 - Communication Overview

To put the pieces together, Figure 3 depicts how the various components are connected and which communication medium they use. The smart meters and the AMIS LSG (switches) are connected to a data concentrator (DC). They communicate via power line data transfer and use an internal protocol. The DC collects this data and forwards it via IP-based communication to the other systems for post-processing. The protocol used is IEC 60870-5-104.

On the other end of the control loop is a PC that controls the transformers and currents sinks via a USB connection. If necessary, these devices can also be used as sensors. The PC is the host for the simulation environment and has a display attached to it.

In between several different post-processing units are installed. An embedded PC resembles a controller for a smart secondary substation node. It sends commands to the PC in the IEC 60870-5-104 protocol. A meter data management (MDM) system collects billing relevant data from the meters. Data can be read from its data base and used for the simulation and post processing in the PC. The control center (Sicam 230) is primarily used for displaying purposes but could also send commands to the PC and the DC.

USE CASES

Currently, the pilot system is used to develop different approaches to voltage-band-regulations in LV grids using the available smart meter infrastructure. The integrated metering infrastructure can also be used to develop monitoring issues like measuring synchronously voltage, active and reactive power [5]. The configuration and setup of prototype equipment for real world demonstrations are tested with the pilot system first and can then be used in real environments. Another topic is the analysis of existing communication architectures. The following five use case show various possibilities for research and development topics that the pilot system can support.

Smart Metering

This use-case is used to verify the basic functions of the pilot system. It includes all elements shown in Figure 3 but does not add the complexity of a simulation. In case of the AMIS System, data is read from the smart meters in two modes: EGDA and PSS. EGDA – express grid data acquisition – reads from a selected number of smart meters as fast as possible and as often as possible the voltage levels from all three phases. This can be used for example for the more complex use case smart secondary substation. PSS – power snapshot – collects various measurements from every smart meter (including voltage, active and reactive power, etc.). This can also be used in topology detection.

Smart Secondary Substation

This use case is extracted from the OpenNode project [3]. The substation is equipped with an (emulated) transformer that can change its tap position frequently. Based on the EGDA readings from the smart meters, the algorithm running on the embedded PC determines the optimal tap position. If changing the tap position is not possible – in case of a spread or max/min position has been reached – voltage band violations can be removed by sending active power limitations to the photovoltaic systems.

Topology detection and change detection

An important issue in low voltage urban grids is the positions of its switches. This use case provides a test-bed for various algorithms to determine the configuration of the grid based on meter readings only.

Effects of large neutral wire currents

Each smart meter measures its local values for voltage, power, phi, etc. The phase shift between two sensor nodes cannot be determined directly. This use case focuses on the combination of real meter readings with simulations of the grid to generate synthetic measurements.

Virtual Power Plant and Grid Control

Another topic for the pilot system is the combination of the virtual power plants and grid control. The two generators can be combined to one virtual power plant and both together have to fulfill contracts in presence of four autonomous consumers. The grid controller has to keep the grid stable under the condition of a maximum availability of the power plant.

Co-Simulation

The pilot system itself provides an analog simulation of a very small low voltage grid with four houses. What it lacks is the possibility to simulate large scale networks with several hundred houses. A software simulation can provide this but lacks the challenges of the real world in terms of communication delays, sensor errors, etc. This system can be used to run a hardware/software co-simulation.

SIMULATION ENVIRONMENT

The simulation environment provides everything that is needed to implement a use case.

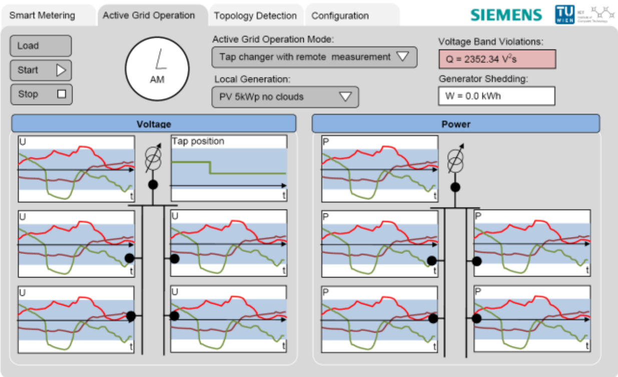

Figure 4 - Smart Secondary Substation Interface

It sets the system time and the speed of the simulation. Based on the time a load and production profile is processed for all transformers and current sinks. A typical setup is that the sun rises at about eight in the morning and sets at seven in the afternoon. The photovoltaic systems produce energy direct proportional to the rising and falling sun. The houses use one of the standard profiles. User interface elements help to control the flow of the use case. For example, different tap changer algorithms can be selected online.

OUTLOOK AND CONCLUSION

The feature to apply distributed control systems for low voltage smart grids in a real hardware environment renders the pilot system as an essential platform to test networked control systems shortly before they are installed in pilot field tests. Even if the system complexity (only a few nodes) and behavior (scaled system, different timing behavior) does not exactly model the real-world situation, the system is equipped with the real-world communication interfaces control components. The process of deployment and configuration of prototype-stage control concepts for active grid operation can be played through with the pilot system and improved. Also newly designed hardware components can run through a first functionality test. An important future topic – the integration of Smart Buildings into the Smart Grid – will be included into the pilot system by a fourth cabinet. It will resemble a typical Smart Building with PV generation, e-car charging station, a building automation system and a building energy agent. Furthermore, new intelligent control strategies for functional buildings can be tested. This will allow the investigation of the dynamics of the interaction between a Smart Building and the Smart Grid.

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