Low-voltage grid automation - Lessons learned during field tests Großschönau, Austria Impulses from project iniGrid

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Abstract –Automation of energy distribution in low-voltage distribution grids is still in its infancy. Sophisticated software and hardware components are, therefore, required in order to promote the automation concepts, such as self-diagnostic and optimization routines, early warning systems, and smart consumption (demand side management). This paper presents a customer energy management system (CEMS) to optimize operation of a building by utilizing newly developed SmartBreakers. Within the scope of a field test, potential for considerable energy saving induced by the usage of the CEMS is shown.

1. Introduction

As a consequence of massive integration of renewables [1], active capacity management of distribution grids has become necessary to tackle the associated issues. These include, for example, unpredictable energy fluctuation, voltage instability in rural grids, and overloading the transmission capacity of feeder lines in order to avoid high investments in grid reinforcements. Management of power line usage in bottleneck situations, as well as fault detection and fast service restoration, are possible only by monitoring the current state of neuralgic nodes in the distribution grid and by controlling associated loads, generators and energy storages. This requires not only an significant upgrade of the ICT infrastructure but also new grid components with monitoring and control functionality.

A broadly assembled consortium of nine project partners collaborate in the Austrian flagship project "Integration of Innovative Distributed Sensors and Actuators in Smart Grids" - *iniGrid*. The partners include four industrial partners: Eaton Industries, Infineon, Zelisko and Sprecher Automation, three academic partners: Austrian Institute Of Technology, Vienna University of Technology, and University of Applied Sciences Upper Austria, one grid operator: Linz Strom, and MOOSMOAR Energies for economical consideration. The aim of this project is to develop and validate innovative sensor and actuator components for smart distribution grids. One key innovative approach in the scope of iniGrid is the integration of the power management and grid protection functions within one device called *SmartBreaker* [2]. In combination with a Customer Energy Management System (CEMS), the feasibility and future economic benefits of the comprehensive solution are demonstrated. To accomplish this, a field test has been conducted.

2. SmartBreaker Concept

The working principle of the SmartBreaker is based on hybrid switching technology. This means that each pole of the breaker is designed as "hybrid switch" which comprise an electromechanical bypass relay and a semiconductor switch (IGBT) in parallel. A serial separation relay provides the required galvanic separation between the line and load sides, as shown in the left-hand side of Figure 1.

Similar to a conventional low-voltage circuit breaker, the SmartBreaker primarily serves to protect electrical power systems by detecting abnormal conditions, such as overloads, short circuit currents, residual currents, and over-voltages and, consequently, interrupts the circuit automatically and safely if any of these conditions are met. Due to its novel design, the SmartBreaker can additionally act similar to a contactor switch, allowing very high switching cycles at nominal current that are needed for everyday power switching in power management applications. Furthermore, the SmartBreaker provides a remote control functionality in order to switch a circuit on and off remotely. The device also includes smart meter functionalities, such as power/energy monitoring and load profiling. These offered features perfectly meet the customers' requirements for an anticipated smart grid scenario.

Figure 1 illustrates a 3D model of the current SmartBreaker design. It shows a 2-pole circuit breaker with a nominal current of 45 A and a short circuit current interruption capacity of 10 kA. It also features a wireless communication to a remote terminal unit (RTU) which serves as a link to a higher-level system. In the current project the RTU is a part of the CEMS.

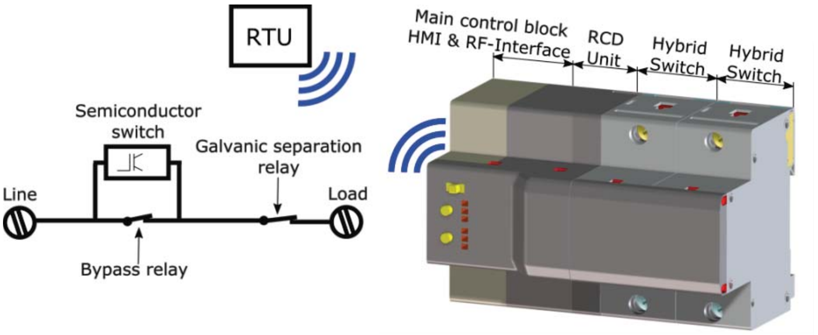


Figure 1: Basic principle and 3D model of the SmartBreaker (HMI… human-machine interface; RCD Unit…residual current device).

3. Customer Energy Management System (CEMS)

The CEMS provides a goal oriented local intelligence that aims to utilize the available hardware towards local consumption optimization. This section will give a short overview of its physical- and software-components.

3.1 Physical Components

The CEMS has been implemented using a Raspberry Pi 3, a relatively cheap but stable off-the-shelf platform that allows for a quick and simple setup. Since the CEMS's communication runs entirely via Ethernet, either via secure tunnels to the remote site in Vienna or via the ECI to the local devices in Großschönau, see Figure 4 for an overview. The Pi already provides all the communication interfaces required for the field test. A small touch screen was connected directly to the Raspberry Pi, to provide feedback and configuration capabilities to the user via a simple web interface (see Figure 3).

3.2 Software Components

As mentioned earlier, the control software aims to optimize local consumption towards a user-defined goal, reducing the local energy consumption. Follow up implementations could extend the solution by integrating local production from photovoltaic systems or reducing the energy cost further by combining price forecasts with battery systems. Driven by three use cases presented in section 4, a separate control strategy for each case was developed, optimizing the possible impact in each situation while simplifying the implementation process. The separate control strategies are bound together by a simple meta-controller that acts as interface to the shared communication layer. For the communication layer, we re-used an existing implementation based on the freely available OpenMUC framework [3]. Detailed description of the communication layer would go beyond the scope of this work but for more information on its implementation details see [4].

Figure 3 illustrates the three control algorithms as activity diagrams. Algorithm A covers the requirements of use case 3 and provides a simple reactive closed control loop based on binary sensor activity. The user can configured the algorithm to use an arbitrary amount of (binary) input sensors and a single SmartBreaker. The algorithm will allow power flow over the breaker as long as any of the sensors is active and the user can additionally configure an optional follow up time, that will allow power flow over the breaker for a certain time after the last sensor was switched to inactive.

Algorithm B extends Algorithm A by wrapping the control into an open control loop that allows the configuration of an operation period for the reactive control. This algorithm is used to cover the requirements of use case 2.

Algorithm C is specifically designed for controlling the ventilation system, as requested by use case 1 and is based on algorithm B. It extends the reactive functionalities of Algorithm A and the operation period of Algorithm B with reactive control to an air quality sensor and timeout control. The timeout control refers to the systems functionality to enable the ventilation if it was not active for a configurable amount of time, even if no violation of the air quality was detected. This provides a proactive step towards good air quality that attempts to avoid the problems caused by the expected delay between the change in air quality caused by a sudden increase in visitors, the detection of the change and the time it takes for the ventilation system to actually impact the air quality in a large room. The binary sensors connected to this controller can be triggered by the user via physical switch to manually engage the ventilation system, should the air quality and timeout based controls not suffice to keep the air quality comfortable.

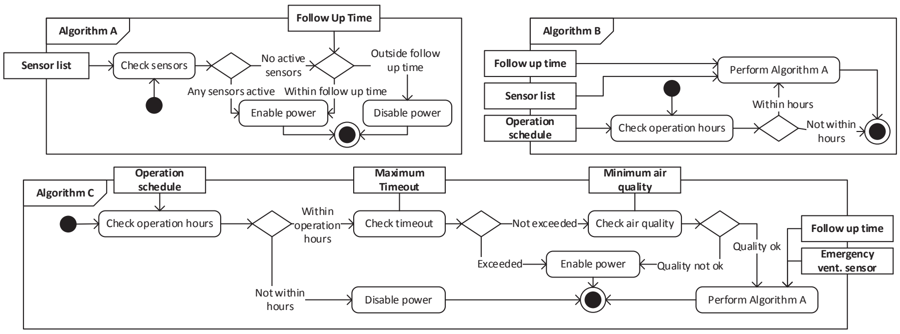
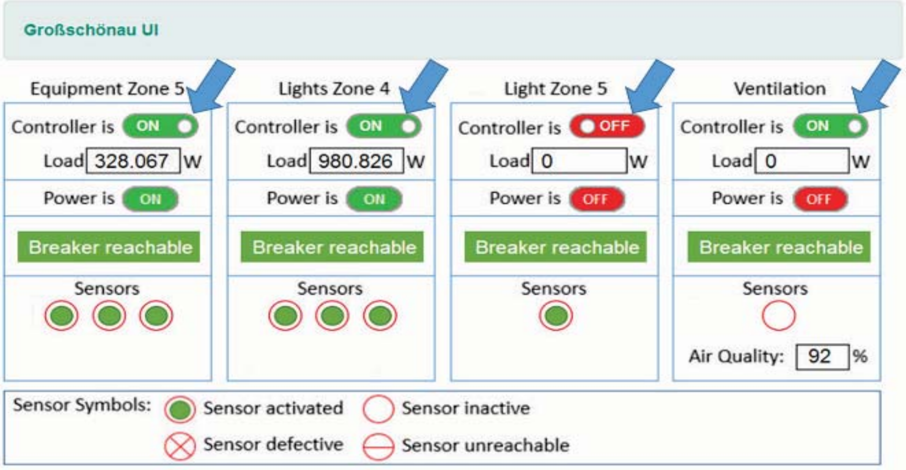


Figure 2: Activity diagrams for the three control algorithms

To give the user access to the current system states and the ability to activate or deactivate the automated controls individually, a custom tailored, simple web interface for the CEMS, displayed on the touch screen, was implemented. Figure 3 shows a screenshot of this interface. Components a user can interact with, has been marked by blue arrows. The only direct interaction available on this interface are for enabling disabling the automated control algorithms. Please note that controller 3, labelled “Light Zone 5” was intended for a fourth use case that is not implemented yet.


Großschönau UI

Equipment Zone 5	Lights Zone 4	Light Zone 5	Ventilation
Controller is ON	Controller is ON	Controller is OFF	Controller is ON
Load 328.067 W	Load 980.826 W	Load 0 W	Load 0 W
Power is ON	Power is ON	Power is OFF	Power is OFF
Breaker reachable	Breaker reachable	Breaker reachable	Breaker reachable
Sensors ● ● ●	Sensors ● ● ●	Sensors ●	Sensors ○ Air Quality: 92 %

Sensor Symbols: ● Sensor activated ○ Sensor inactive
⊗ Sensor defective ⊖ Sensor unreachable

Figure 3: CEMS user interface (interactive components marked by blue arrows).

For the parameterization of the controllers, the system also offers an administrative mode that gives direct access to the values administered by the OpenMUC framework, including all configurable parameters, directly via the web interface.

4. Field test

As part of the iniGrid project, a CEMS for an energy customer domain has been set up in the course of a field test. The field test is conducted over a period of three months and is still on going at Sonnenwelt museum in Großschönau, Lower Austria [5] where visitors are taken on a journey through time covering the complete history of energy production, harvesting and, storage. The aim of the field test is, on the one hand, to gain practical experience with the implementation of the CEMS and especially the integration of the SmartBreaker into an existing IT network and power grid infrastructure, and on the other hand, to demonstrate the functionality of the CEMS and to highlight the possible energy savings potentials.

4.1 Setup

Figure 4 shows a schematic overview of the components used during the field test. It can be seen that a Supervisory Control and Data Acquisition (SCADA) system located in Vienna interacts with the CEMS located in Großschönau. The Ethernet communication takes place via a certificate based secure VPN tunnels as specified by VHPready Alliance [6]. The CEMS is utilizing the local available sensors and actuators i.e., the SmartBreakers, motion detectors, and an air quality sensor meter via an Ethernet communication interface (ECI). The ECI represents the link between Ethernet and a proprietary 868 MHz wireless network protocol based on the IEEE 802.15.4 standard [7]. The wireless communication within the field test site is marked with blue dotted lines in figure 4. The CEMS, guided by a local intelligence, connects and disconnects local loads i.e., the ventilation, multimedia system, and lighting via the installed SmartBreakers as described in section 3. The field test covered three use cases in total, which are aiming to exemplify different aspects of a possible automated control system.

Use case 1 covers the ventilation system and combines reaction to analog input sensor values, with various time constraints and a manual interaction option for the user. Use case 2 covers the demand driven activation of a multimedia system during an operation period. Use case 3 has the lowest control complexity and turns a number of lights on and off, depending on activity monitored by a set of motion sensors.

Use Case 1 requires the CEMS to integrate with the ventilation system available at the testing site. The user requires the ventilation system to keep the air quality in the exhibition halls to a comfortable level. The existing solution activates the ventilation system in fixed intervals and offers the possibility to trigger additional ventilation periods via a command interface. Our solution was required to still provide this base functionality consisting of periodic and manually triggered ventilation, but extend it by reacting to output from an air quality sensor mounted in the exhibition hall. Due to this reactive functionality, the delay between the regular ventilation cycles can be extended, in order to safe power during longer periods of inactivity in the exhibition hall.

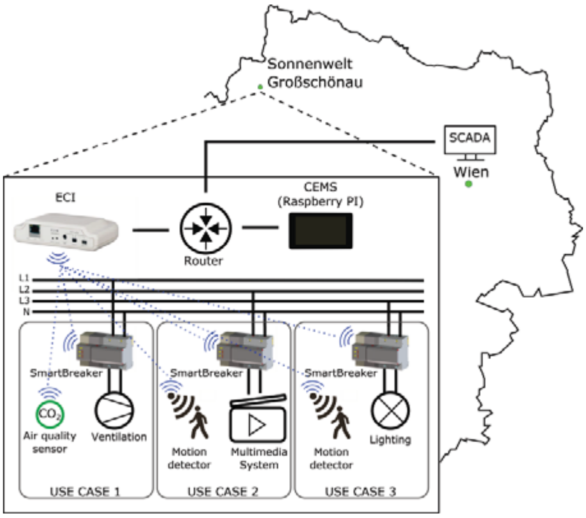


Figure 4: Schematics depicting the field test.

Use Case 2 connects the existing PCs and monitors in one area of the exhibition halls, to the existing motion sensor system installed in the same area. In the original setup, output of the movement sensors activated only the lights in the respective area. Use case 2, requires our system to interact with the existing movement sensors, by listening on the existing signal line used to enable or disable the lights in this area. We used binary sensors that inform the CEMS whenever the control line goes to an active (high) state. In these cases, and only within the operation hours of the exhibition, the CEMS should start a set of computers, showing the various multimedia presentations. Time issues when staring the involved hardware, required the integration of motion sensors from surrounding areas, in order to ensure that visitors immediately had access to the multimedia content upon entering this part of the exhibition.

Use Case 3 requires the CEMS to turn the light whenever anybody enters the exhibition hall. In contrast to the previous use cases, this use case is not bound by the exhibitions operation hours but needs to react during any time of the day. For this use case, we did not interface with the existing sensor equipment available on site, but instead used additional motion sensor that are directly accessible via the ECI.

4.2 Implementation

The practical implementation of the field test setup is shown in Figure 5. The left-hand side image illustrates the enclosure cabinet which contains four SmartBreaker (1) (three in use, one is a reserve), the ECI (2), a router (3), and a Raspberry Pi 3 (4). The CEMS is implemented on the Raspberry. The right-hand side, on the other hand, symbolizes an exhibition hall at the museum where four motion detectors (5) and an air quality sensor (6) are installed at suitable positions. Since the exhibition hall is physically separated from the enclosure, a RF router (not shown in the figure) is used in order to provide a sufficiently high RF signal strength.

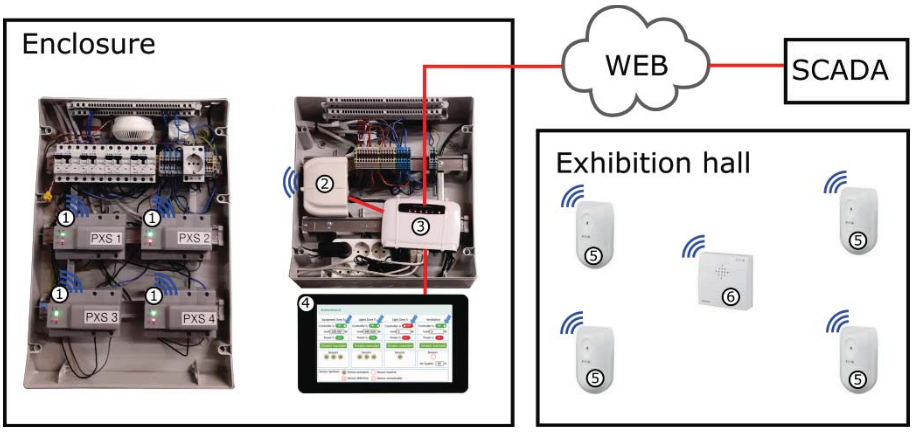


Figure 5: Practical implementation of the iniGrid setup: 1…SmartBreaker, 2…Ethernet Communication Interface (ECI), 3…router, 4…Raspberry Pi (CEMS), 5…motion detector, 6…air quality sensor, (((…radio link, —…tethered Ethernet connection

Results

For the evaluation of the efficiency of the CEMS, the total energy consumption with and without the CEMS control are compared, as shown in Figure 6. The evaluation period is set to 31 days. The baseline (the left-hand side pair of columns) represents the total energy consumption (in kWh) when the CEMS does not control the ventilation (blue column) and the multi-median system (red column), respectively. The right-hand side pair of columns represents the power consumption when the CEMS is controlling the ventilation and multi-median system.

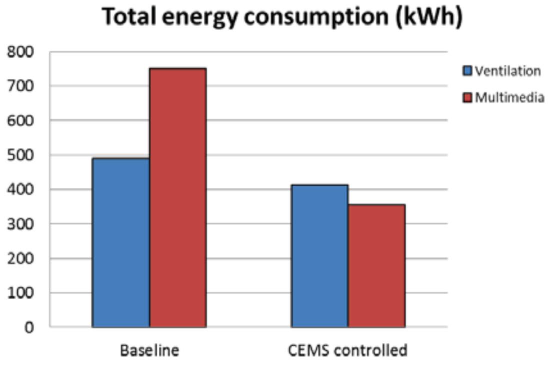


Figure 6: Comparison of total power consumptions with (right) and without (left) CEMS control.

A reduction by over 50 % of the multi-media energy consumption and, therefore cost can be observed. The energy consumption of the ventilation has been reduced by 15 % due to the usage of the CEMS. The contribution of the CEMS hardware (including the three Smart-Breakers, ECI, Raspberry PI, and all sensors) accounts for only 0,3 % of the total power consumption. With this setup, the projected total cost savings per year amount to approximately €650. Assuming investment cost for this setup, including hardware, software and labor of about €4000, a payback period of 6,1 years can be expected.

5. Conclusion

Within the research project iniGrid the feasibility and efficacy of a CEMS controlled building optimization system utilizing SmartBreakers is proven in field trials in real life scenarios. The field test additionally revealed high potential for energy consumption savings in buildings Savings up to 50 % in energy consumption have been achieved.

6. Acknowledgement

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