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Cellular Smart Grid Platform (CSGriP) Demos

Demonstration set-ups

Ballard Asare-Bediako Redouane Eddeane

Cellular Smart Grid Platform (CSGriP) Demos

This report summarizes demonstration setups developed at the HAN and Avans Universities of Applied of Science to test the Cellular Smart Grid Platform concept. The setups serve as preliminary studies and inputs to the final design and testing of the main CSGriP project. At the HAN was CSGriP demonstration setup built to investigate the key parameters and control strategy for a Microgrid having the CSGriP features. Also demand-side management with smart meters were investigated. Further, the HAN in collaboration with Alliander developed and tested a smart electric vehicle charging system using CSGriP features.

At Avans, a home automation systems was developed that uses the inherent frequencies control property of the CSGriP. Also other control properties and human behavior aspects were analyzed.

The results from these demonstration setups are taking into account (either partly or fully) in the final CSGriP design.

1. Microgrid Frequency-based Control Demo

To evaluate the behavior of a CSGriP Microgrid (cell) with a Voltage Source Converter (VSC), the HAN demonstrator (see Figures 1 & 2) was utilized for performing tests. The tests involves Isolated / Stand – Alone and Grid-Connected states, to identify the parameters required for possible interface for developing control strategy for the main CSGriP test set-up, and for evaluating the influence of these parameters in the operation of the converter. The Single Line Diagram (SLD) of the test setup is depicted in Figure 3 below.

1.1. HAN CSGriP Demonstrator

The HAN Cellular Smart Grid Platform (CSGriP) demonstrator is a test setup to provide load management functions where battery storage system will be emulated using a back to back inverter connected to the grid. Figure 1 shows the schematic diagram for the system comprising back-to-back DC/AC converters, two isolating transformers, two LC filters, a Siemens PLC, and smart meters.

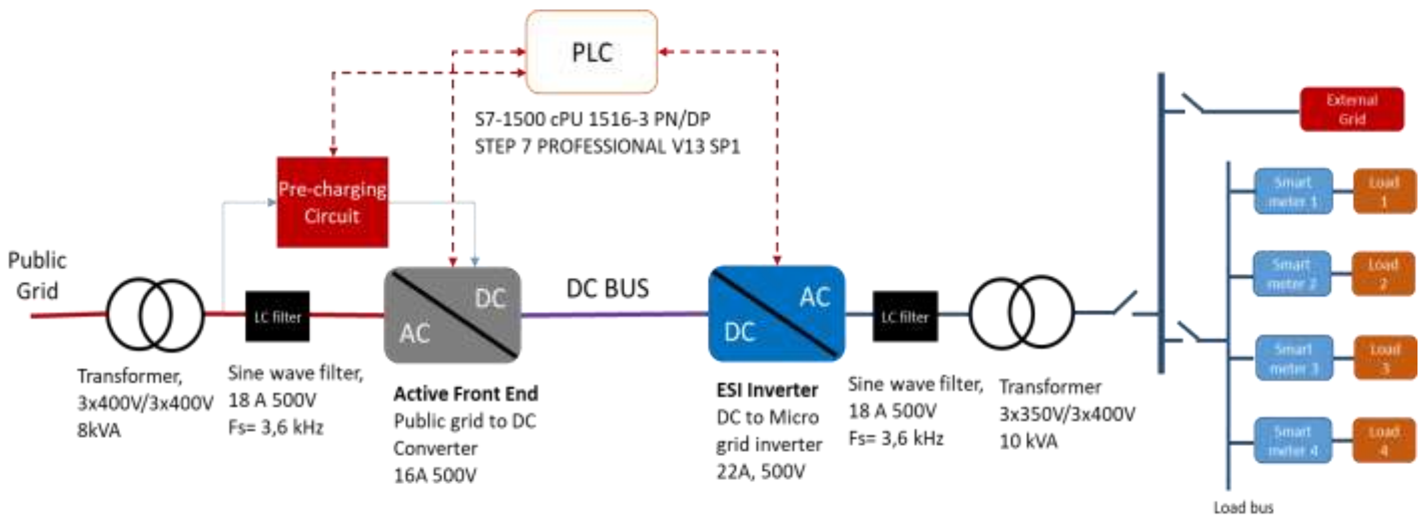


Figure 1: Schematic diagram of the HAN CSGriP Demonstrator

Figure 2: Picture of the HAN CSGriP Demonstrator

Main sub-components and their functions

A. Active Front End (Public grid to DC Converter)
- Connect to normal 3-phase AC grid and emulate a battery
- Control power exchange between grid and ESI converter
- Control DC bus Voltage
- It is Bi-directional to power flow
- It controlled manually via keypad

B. ESI Inverter (DC to Micro grid inverter)
- Grid forming inverter
- Regulates AC bus frequency and voltage
- It is bi-directional to active and reactive power flow
- It is PLC controlled
- It has possibility to set operating frequency manually/remotely

C. PLC control system
- Programmable via MATLAB Simulink
- Monitors and controls ESI activities
- Data gathering from Power meters and ESI
- Remote control functions

D. Smart Meters for Demand-side management

- Switch ON/OFF connected loads based on set priorities
- Use system frequency as control mechanism
- Remote control/communication functions

E. LC Filters

- Prevention of high frequency voltage to and from the grid

F. Isolating Transformers

- Isolating t the powered device from the external grid for safety reasons

System Interfaces

- The AC grid provide power of max 9.6 kW
- Active Front End "charge or discharge" the DC Bus
- Local load bus with consumption of maximally 9.6 kW
- Monitoring and control interface with PLC

Other Specifications:

- DC link bus voltage ranges from 550 – 720 V DC
- AC- bus interfaces operate at 230/400 VAC
- ESI inverter operate at 3-phase, 230/400 V AC 50 Hz, nominal power of 5 kW (max. 9.6 kW)

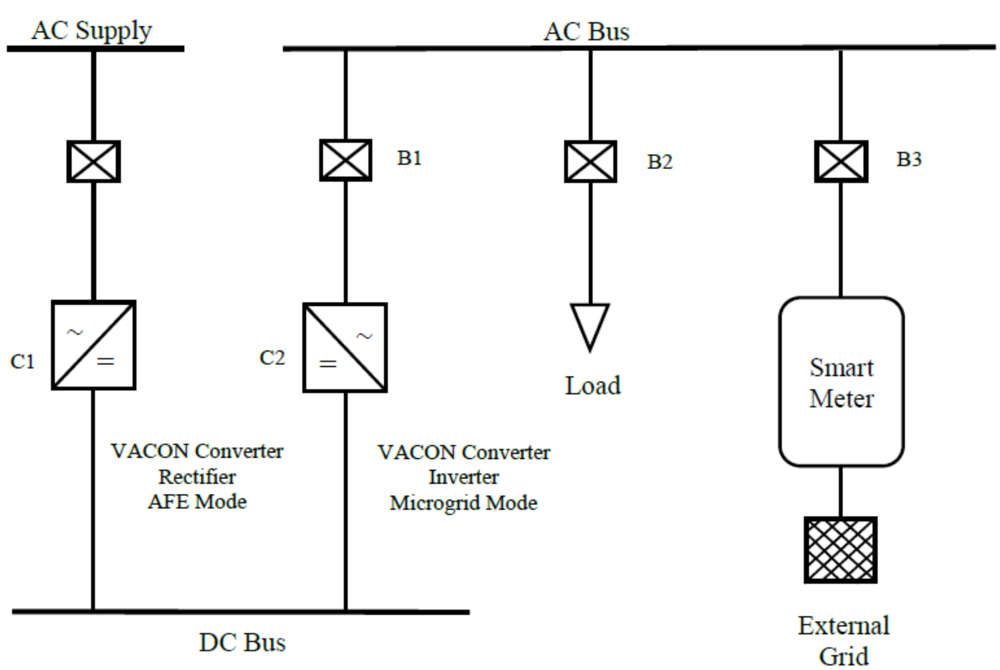


Figure 3: Single line diagram for the demo test.

Converter (*C1*) is used as a rectifier to create a DC Bus while Converter (*C2*) is the main Microgrid inverter to regulate the desired AC voltage and power based on the parameter settings.

1.2. Operating principles

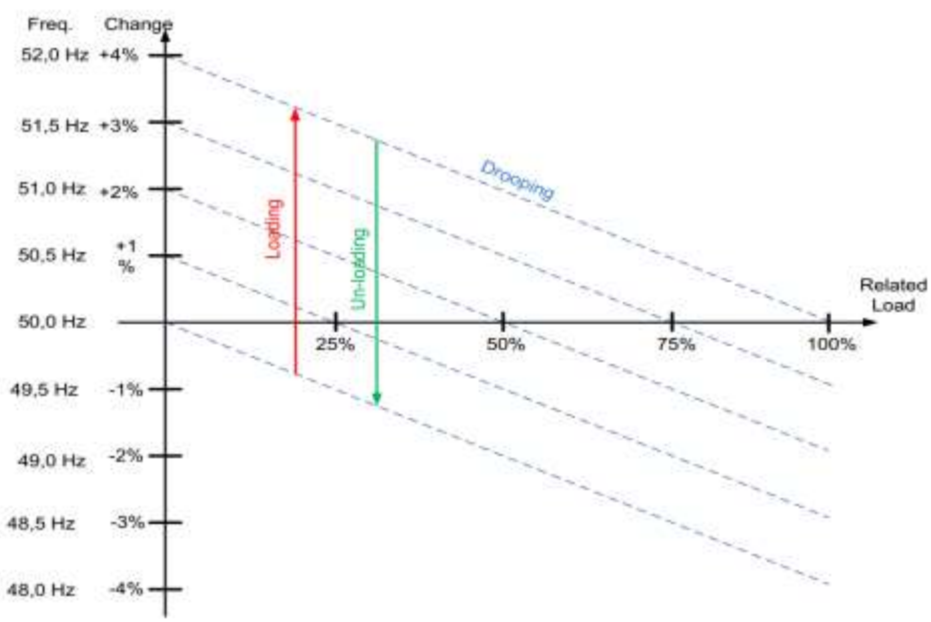
The system is tested in two (2) modes: stand-alone Microgrid and grid-connected modes. In the Microgrid mode, the operating principles of the converter has Droop Speed Control Mode and Isochronous Speed Control Mode. In *Droop Speed Control mode*, for an increase in power demand, the grid frequency drops depending on the load. A command to increase frequency is sent to all generating units to increase their output so that grid frequency is restored to its nominal value. Similarly, as the load decreases, system frequency will increase and subsequently, a command is sent to the generating units to decrease their output power.

In the *Isochronous Speed Control mode*, the Microgrid frequency is same as the grid frequency. If the Microgrid inverter is operating in drooping mode, the power output is controlled by Base Current Reference. This reference is controlled by power management system (PMS) that regulates the power sharing between different machines on the grid.

1.3. Test Parameters

The parameters utilized for performing the tests are summarized below

- *Nominal Frequency* –Base frequency set point of the converter. In Microgrid mode, it is used as a reference point for the Base Current reference and drooping.
- *Supply Frequency* – This parameter defines the frequency output of the converter with frequency drooping.
- *Frequency Droop* – Defines the frequency deviation in Hz with the percentage of loading of the inverter.
- *Frequency Offset* – This parameter is used to adjust the base frequency for drooping purposes. For example, if frequency droop is set to 2 Hz, this parameter can be set to 1 Hz so that when the load is 50%, the frequency will be at the nominal point. The offset can also be set by the supply frequency parameters (see Figure 4).
- *Inverter Power* – Power delivered or absorbed by the converter. The power delivered is considered positive and power absorbed by the inverter is considered negative.



- Figure 4: Frequency Droop curve of the Microgrid inverter

1.4. Test Results - Stand-alone mode

For this test, the Microgrid converter connected only to the (variable) load. This means that the converter is in Isolated / Stand-alone condition capable of delivering power to. At no load, the parameters – Nominal frequency, Frequency droop and Base current reference are varied. The Supply frequency and Power supplied by the converter are presented in Table 1.

Table 1: Stand-alone mode without load

Nominal Frequency (Hz)	Frequency Offset (Hz)	Frequency Droop (Hz)	Base Current Reference (%)	Supply Frequency (Hz)	Power Inverter (kW)
50	-1	1	0	49	0
51	-1	1	0	50	0
50	-1	2	0	49	0
50	-1	2	100	51	0
50	-1	1	100	50	0

A heater of 5kW is connected to the system. Table 2 shows the influence of Nominal frequency, Frequency droop and Base current reference on Supply frequency, irrespective of the load demand.

Table 2: Stand-alone mode with load

Nominal Frequency (Hz)	Frequency Offset (Hz)	Frequency Droop (Hz)	Base Current Reference (%)	Supply Frequency (Hz)	Power Inverter (kW)	Power Load (kW)
50	-1	1	0	49	0	0
50	-1	1	0	48.53	4.7	-4.7
51	-1	1	0	49.53	4.6	-4.6
50	-1	2	0	48.06	4.7	-4.7
50	-1	2	100	50.06	4.7	-4.7
50	-1	1	100	49.53	4.7	-4.7

The results show that as the Frequency Droop is increased, the supply frequency is reduced from its reference frequency, which is defined by Nominal frequency, Frequency offset and Base current reference. This indicates that Supply frequency of the converter follows the droop behavior as per equation below where $f0$ is reference frequency, kP frequency droop and P power supplied by inverter.

$$f = f0 - k_P \cdot P$$

1.5. Test Results – Grid-connected mode

This test is focused on the converters capability of synchronizing with the External Grid. Here the synchronization process is done using the internal sync command with the help of D7 card measurement. Once synchronized, the parameters - Nominal frequency, Frequency offset, Frequency droop and Base current reference are varied to evaluate their influence on the operating behavior. The measured values are noted in Table 3

Table 3: Grid-connected mode with load

Nominal Frequency (Hz)	Frequency Offset (Hz)	Frequency Droop (Hz)	Base Current Reference (%)	Supply Frequency (Hz)	Power Inverter (kW)	Power Grid (kW)	Power Load (kW)
51	-1	1	0	50	0	0	0
51.15	-1	1	0	49.99	1.5	-1.5	0
51.25	-1	1	0	50	2.3	-2.25	0
51.25	-1	2	0	50.01	1.3	-1.3	0
51.55	-1	2	0	50	2.6	-2.58	0
51.55	-1	1	0	50	5.2	-5.15	0
51.75	-1	1	0	50	7.4	-7.2	0
51.75	-1	1	0	50	7.4	-2.1	-4.5
51.75	-1	2	0	49.99	3.8	0.95	-4.5
51.25	-1	2	0	49.99	1.3	3.3	-4.5
51.05	-1	2	0	50	0.3	4.2	-4.5
51	-1	2	0	50	0	4.5	-4.5
51	-1	1	0	49.99	0	4.5	-4.5

From the results, the following could be summarized:

- During synchronization with External grid, the parameters - Nominal frequency, Frequency offset and Frequency droop influence the operation of the converter.
- The power output from the converter is regulated by the drooping behavior - Nominal frequency and Frequency droop.
- Power balance is always maintained within the network. If excess power is generated by the converter than required by the load, the External Grid absorbs the difference and if there is shortage of power from the converter, the External Grid supplies the remaining power required by the load.
- The supply frequency is always 50 Hz (grid frequency).

2. Demand Side Management - Smart EV charger with frequency control (D5.3)

Electric vehicles are growing in the market. They are of strategic importance in increasing the sustainability of car mobility and energy supplies. Use of plug-in (hybrid) electric vehicles is growing across Europe, and so are the charging infrastructures that enable vehicles to be charged at home, workplace or in public areas. However, utilities are becoming concerned about the potential stresses, performance degradations and overloads that may occur in distribution systems with influx of EV charging activities. Uncontrolled and random EV charging can cause increased power losses, overloads and voltage fluctuations, which are all detrimental to the reliability and security a smart grid[1]. Therefore, a real-time smart control strategy is developed to optimize the use energy in a CSGriP cell.

Smart Charging Modes

A smart battery charger is mainly a switch mode power supply (also known as high frequency charger) that has the ability to communicate with a smart battery pack's battery management system (BMS) in order to control and monitor the charging process[2]. In CSGriP project, a smart EV charging system with three charging modes was developed using basic components as given in Figure below:

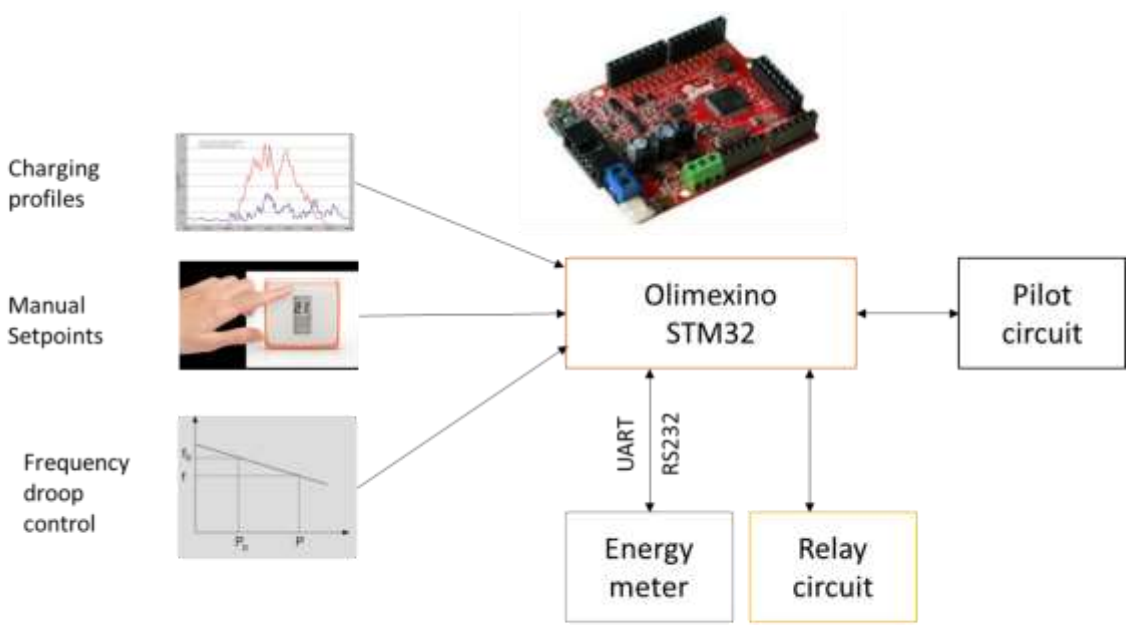


Figure 5: Smart EV charging system for demand side management.

[1] Sara Deilami ; Amir S. Masoum ; Paul S. Moses ; Mohammad A. S. Masoum: "Real-Time Coordination of Plug-In Electric Vehicle Charging in Smart Grids to Minimize Power Losses and Improve Voltage Profile." IEEE Transactions on Smart Grids, Volume: 2 Issue: 3, Sept. 2011.

[2] https://en.wikipedia.org/wiki/Smart_battery_charger

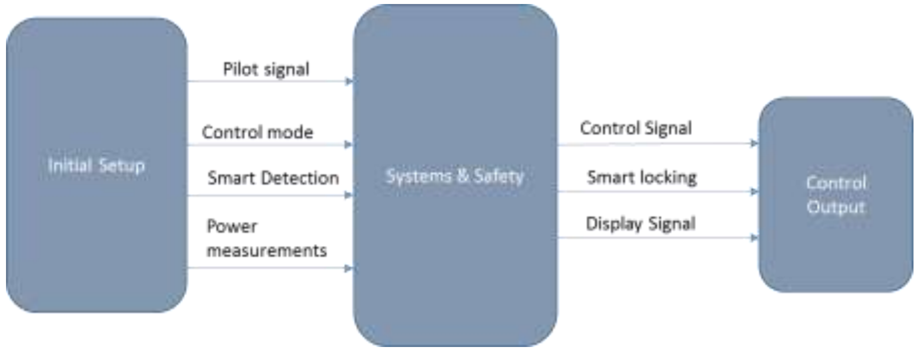


Figure 6: Control scheme for the smart EV charger

Charging profile mode: In this mode, a desired profile on how the customer wishes to charge the EV car is sent to the controller (Olimexino STM32). The controller, using PWM signal communication with the car via the pilot circuit controls the charging of the car as defined by the profile.

Manual setpoints mode: Here the use can set any power charging value of choice as long as this value is within the minimum and maximum charging power ratings of the vehicle. For a single and three phase EV chargers, the value ca be between 6A and 16A, 6A and 32A respectively.

Frequency mode: CSGriP has the frequency as its unique control signal. This means that most connected devices respond to the change in the system frequency. All generation units (including battery with inverter system) in a CSGriP cell use frequency drooping characteristics to control the output power of each unit. Here again, the demand side is also made to consume power based on the system frequency. Figure below shows the drooping characteristics developed for the Smart EV charger. Each of the power limits (Pmin, Pmax, and Pmin) and the corresponding frequencies are easily adaptable, creating high flexibility.

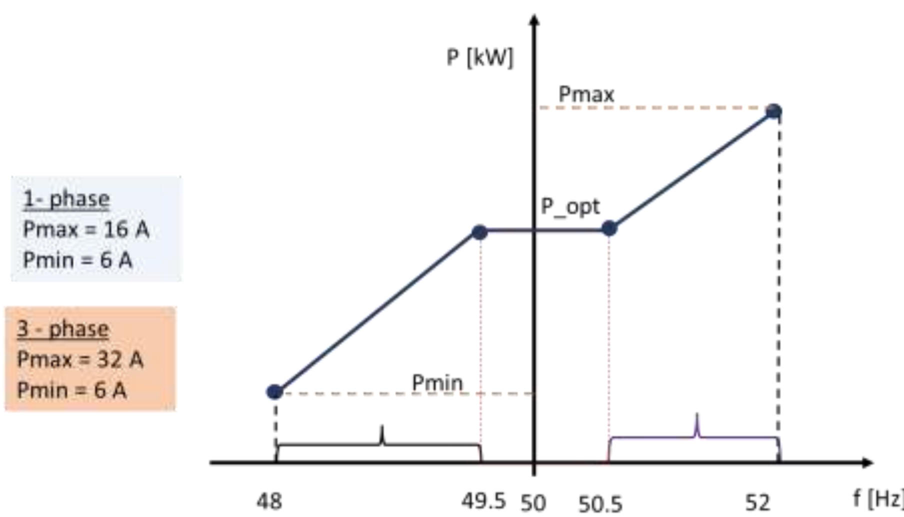


Figure 7: Droop characteristics of the smart electric vehicle charger.

3. Demand side management with Smart meters (D6.5)

In cases where demand has grown faster than production, random power outages may occur. The CSGriP concept focusses on providing the most important users with energy, by shutting of lower priority users when there is not enough power for everyone. This is achieved by providing all users with frequency-controlled smart meters. These smart meters can 'see' the state of the net and switch-off low priority users when necessary. The state of the net is analyzed by measuring the system frequency locally. A lower frequency corresponds to shortage in power production compared to the demand. This, combined with a pre-programmed shut-down frequency on the smart meters can be used to stabilize the net.

A test setup consisting of 5 smart meters and a data collector (which communicates with the smart meters via power line carrier) was connected to a CSGriP cell at the HAN which provided variable frequency for testing. The setup consisted of 5 main components: data, concentrator, 5 smart meters, hand-held unit, keypad, light bulbs (as loads), and a browser interface.

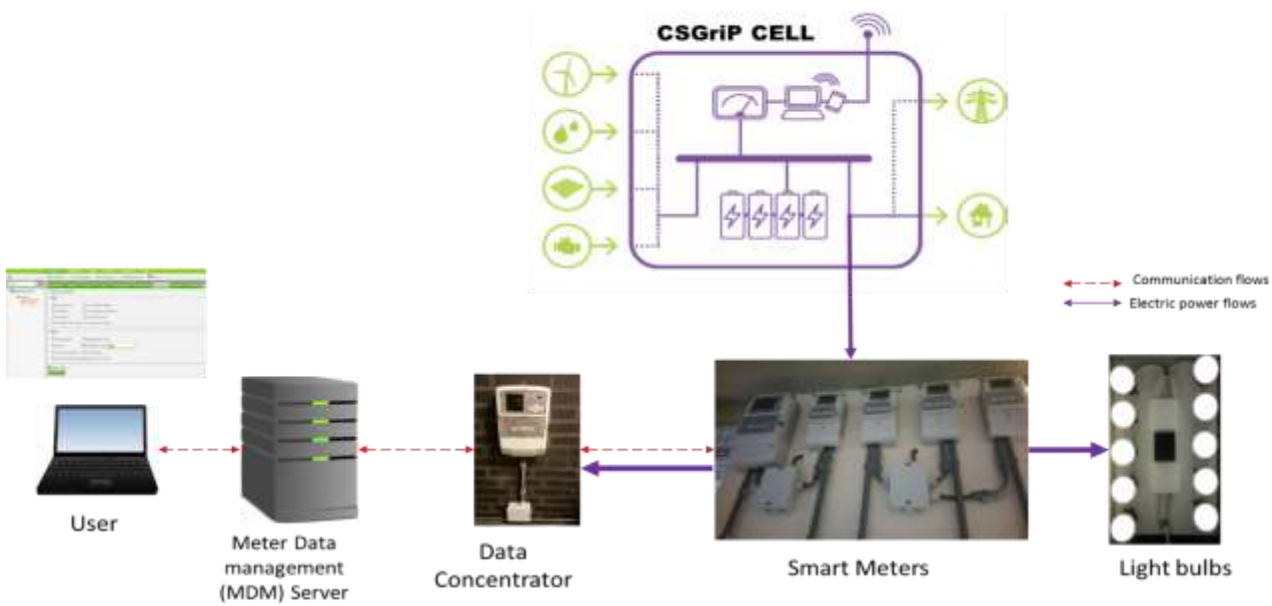


Figure 8: Test-up for demand side management with smart meters.

Test Results

- **Communication test:** The goal of this test was to validate the option to apply settings via the internet browser interface to the smart meters. The following were observed:

Command/ Settings Sent	Meter 1	Meter 2	Meter 3	Meter 4	Meter 5
Date and time	√	√	√	√	√
Switch ON/OFF		√		√	√
Upload credits			√	√	x
Switch Frequency				√	√
Power Limit				√	√

The browser interface commands worked without any problems the settings are successfully set, and tests after that show that the settings actually have been registered.

Time	Command	Response
12:28:46 PM	Get Load Limit Mode	Normal power:False , Critical power:False, Frequency:True , Voltage:False
12:27:54 PM	Get Frequency Status	Meter is not in frequency limit mode: 49.98(Hz)
12:27:45 PM	Get Frequency Settings	Minimum Threshold: 49 (Hz) Return Value Threshold: 50 (Hz) Threshold Exceed Time: 25 (20 mSec) Threshold Return Time: 25 (20 mSec)
12:27:32 PM	Set Frequency Settings	Frequency settings set successfully

Figure 9: Frequency switch settings

- **Frequency based switching test:** The meters were set to turn off at <50.5Hz and switch on at >51Hz. The meters correctly switched at these points, so the system is assumed to work correctly.

- **EMC Compatibility:** The setup has been made with 10 LED lights, each with its own controller. The plan was to cause harmonic disturbances on the net and to test its influence on the power line communication.

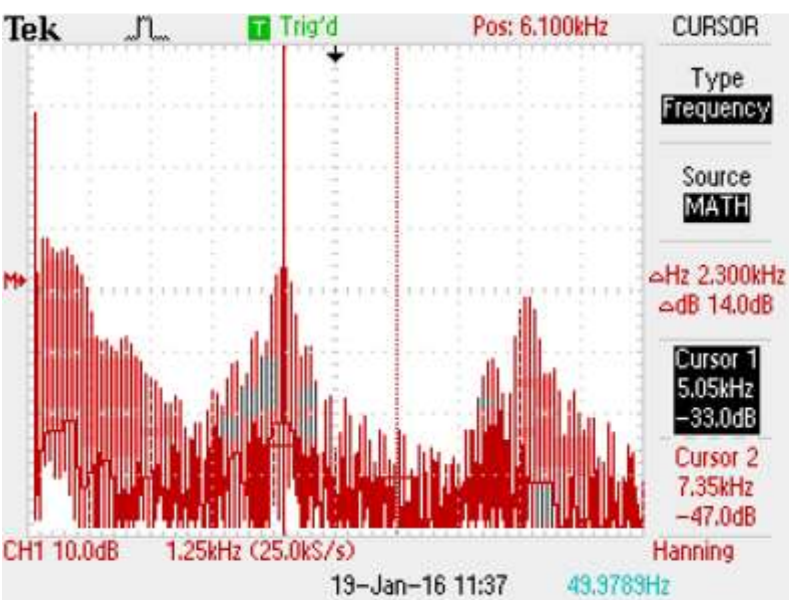


Figure 10: FFT for the LED loads

Frequency spectrum peaks can be seen at 5 kHz and higher harmonics. The communication time went from 2 seconds to 2.5 seconds due to the disturbing loads. Power line communication works at a frequency between 100 kHz and 200 kHz, so a source which works at that may yield different results.

4. Home automation applications with CSGriP functions using standard components (D4.5)

4.1 Introduction

In this report the efforts will be described of extending the frequency-based demand-side control concepts developed within the CSGriP (Cellular Smart Grid Platform) to home automation systems and user behavior.

Renewables such as wind power and photovoltaics have changed frequency control. First, because these resources are intermittent, they cause short-term balancing issues that has direct bearing on frequency. Second, these renewables do not function in the same way as conventional frequency control services. Sun and wind resources cannot be turned on or off to adjust the system frequency, like water flowing through a hydro installation.

To implement CSGriP (Cellular Smart Grid Platform) decision technology mains frequency needs to be monitored. Mains frequency is influenced by (power) load, dropping when the mains load increases. This input parameter is needed to control mains power load (and switching) using Rule-bases engines in modern (open source) Home automation platforms.

Specific objectives:

- Determine accurate mains frequency using low-cost technology.
- Mains load control based on rule-based engine in modern, open source home automation platform
- User behavior as a control for demand-side management.

4.2 Study user behavior and home automation (D4.1)

A smart grid includes the technology that enables a community to generate its own energy, but also to self-regulate supply and demand of sustainable energy within that community. In order to be successful with this self-regulation one has to manage the energy usage of its members. This behavioral component is the main theme of this study.

The report (CSGriP report 4 AVANS gedragscomponent_DEF) describes two studies on energy usage by employees within an organization and the possibilities to influence their energy usage behavior. The first research explores the current attitude and behavior of employees regarding energy in relation to their energy usage, and more specific their ability and willingness to save energy. The second research examines which communication interventions enhance more energy efficient behavior of employees.

Research methods used contain literature studies, quantitative field research (pilot interventions), expert interviews with stakeholders, and in-depth interviews/ panel discussions with employees. Research is conducted at a location of Avans University of Applied Science.

The first study indicates that the way users go through a choice process is important for the intentions to conduct a certain energy behavior. Incentives are an encouragement to achieve intentions, but it seems that organizational circumstance affect the process strongly. Energy saving turns out to be a current and conscious topic for our target audience in their domestic environment, but the domestic behavior does not automatically transfer to desired energy behavior in the organizational setting, i.e. Avans. The direct urge and benefits of saving energy is absent at work, and a direct motivation for saving is lacking. However, providing financial benefits, a great stimulus in the home situation, is hardly effective in the work environment. Feedback is the biggest motivator, when the user is being addressed on his behavior immediately. However, encouraging to save on energy only works if the intentions of the organization and the conditions of the building are energy-efficient. Perceived shortcomings will be demotivating.

The second research indicates that employees of Avans (at the test location) are hardly aware of Avans' activities concerning sustainability. Hence they are not motivated to save energy.

Literature mentions feedback, prompting and communicating injunctive and descriptive standards as most successful interventions. The field experiment on printing machines shows that a prompt (effecting less printing) was effective for a number of weeks before flattening. Posters and newsletters were less effective, though some respondents indicate that the background information made them more aware of their energy behavior. The combination of all methods indicates that three factors impede on conscious behavioral change: lack of clarity about employee expectations, fragmented organization when promoting sustainability and a perceived lack of control due to a building that is much automated.

Recommendations for follow up research: comparable research on a larger scale and longer term,
research on other interventions and the influence of social norms within an organization, and generalization by retesting in different types of organizations.

4.3 Technology review commercial systems (D4.2)

System frequency indicates the balance of generation and demand in a power system. Within the CSGRIP project the power system requires the frequency to be maintained at 50Hz ±4%. Apart from using generation, changes in demand are useful for supporting the frequency. Electrical loads which are time-flexible can be interrupted for a certain period of time or can be dimmed. Such appliances are able to participate in primary frequency response. There are several control methods to manage the behavior of load according to system frequency. Direct Load Control (DLC) of the domestic loads to provide primary frequency response using exiting home automation systems was investigated.

Functional requirements

Two-ways wireless connection is required to determine working functionality of connected sensors and actuators. It is also desirable to have data transfers with (some kind) of error detection, preferable build in the transmission protocol.

Open standard communication protocols make it possible to use tools and hardware from several sources. The Wireshark application is a very capable network analyzer that only works with open standard communication protocols.

Commercial available, 'off-the-shelf' sensors and actuators. Focus of the project is not to design and build smart sensors.

To extend functionally it is preferable to have internet connectivity so other data sources can be incorporated.

Extendable (software functionality). Most preferable is some kind of interface to extend functionality. This can be achieved by using open-source software or by e.g. documented libraries.

For the CSGriP project the most used 'systems' have been looked at:

Table 4: home automation systems comparison

System (software) naming	License / cost	Runs on Raspberry PI (Linux)	User- and install base
OpenHab	Open source	Yes	Great
Domoticz	Open source	Yes	Great
PiLight	Open source	Yes	Medium
PiMatic	Open source	Yes	Medium
HomeWizzard	Closed / 250 Euro	Dedicated hardware (box)	Medium
Fibaro Home Center (v2)	Closed / 550 Euro	Dedicated hardware (box)	n.a. / unknown
Plugwise	Closed	Dedicated hardware	n.a. / unknown

All one-way (wireless) communication standards for ISM 433MHz application are not suitable in the CSGriP application. The HomeWizzard system is built around this kind of low cost sensor and actuator technology.

The Fibaro Home Center uses Z-Wave as communication protocol. Z-Wave (868MHz) is an advanced open protocol with encryption, routing and bidirectional communication build in. Although the Fibaro Home Center is closed source all Fibaro sensors and actuator are usable in other Z-Wave bases domotica applications. E.g. the Fibaro plugs can be used for power measurements and –switching. Routing is available to achieve scalability.

Conclusion: Z-Wave technology is the most appropriate in the CSGriP application

From all the open source home automation application, the Domoticz application has the largest user install base. Developers are releasing new features on a regular base and bugs are solved within short time interval. The PiMatic system also has large groups of users but is 'less' mature than Domoticz. OpenHab is 'a new promising kid on the block'.

The Domoticz application is most appropriate in the CSGriP application.

Combining Domoticz and Z-Wave

The Domoticz application, acting as the home automation system is deployed on a Raspberry Pi V3. A RaZberry Z-Wave extension board is connected to the Raspberry Pi V3 extension header. The Domoticz application is able to communicate with the RaZberry board using open source RaZberry hardware drivers.

Figure 11: Razberry Z-wave extension for Raspberry PI

Fibaro Z-Wave sensor (plugs) and actuators can be connected to the Domoticz application using the open Z-Wave protocol. The rule-based decision functionality of the Domoticz application can use sensor data to drive actuator.

De Domoticz system can also be used as data server for other applications using (RestFul) API internet technology.

4.4 Test set-up and testing of selected devices (D4.3)

As mentioned previously system frequency indicates the balance of generation and demand in a power system. Within the CSGRIP project the power system requires the frequency to be maintained at 50Hz ±4%. To achieve this an accurate frequency measurement (<5ppm) with off-the-shelf components has been developed.

The CSGriP project requires a short-term accurate mains-frequency determination (<0.1Hz) in the range 48Hz to 52Hz within a 10°C to 30°C temperature range.

Multiple solutions to this achievement exists ranging from analysis in the frequency domain (e.g. digital FFT which requires long period of sampling to achieve the required accuracy) to (analogue) PLL techniques (which also requires an accurate frequency source)

Triggered by [1] to achieve low-cost mains-frequency determination with off-the-shelve components the Maxim DS3231 Extreme Accurate RTC (Real-time Clock) chip was selected to prototype build an accurate powerline frequency measurement circuit with short measurement times (<1s). Key to the solution is the availability of the < 3.5ppm 32.768kHz square wave output (-40°C to 85°C). The chip is factory calibrated and contains a temperature compensated internal oscillator. The timekeeping functions of the RTC chip are not used.

The schematic is illustrated in figure 12.

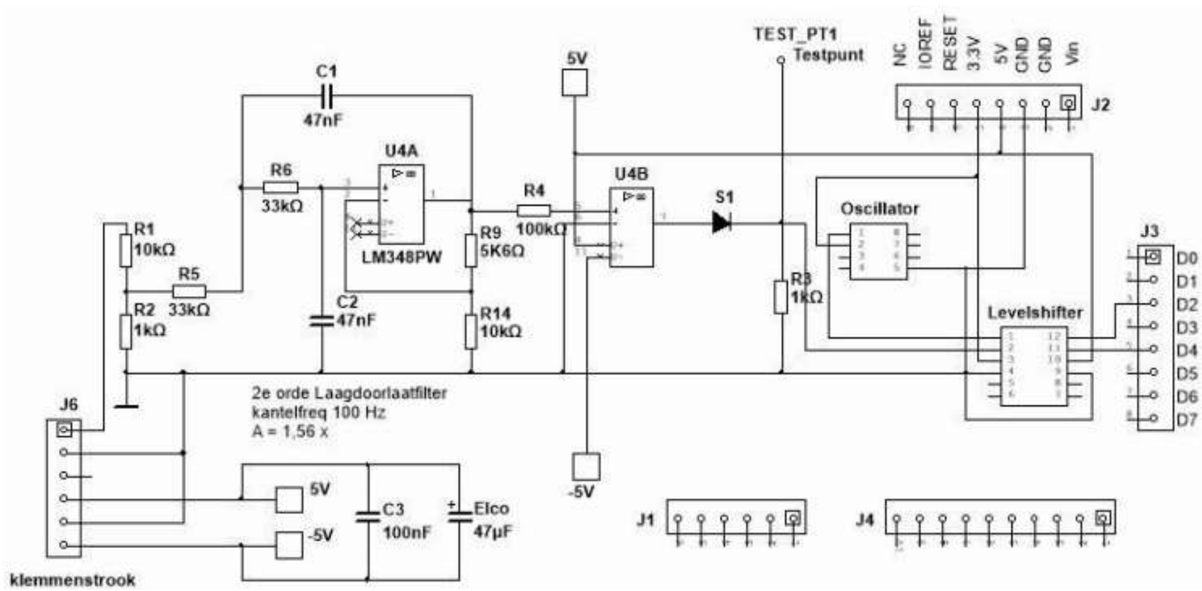


Figure 12: mains frequency measurement circuit

Working principle

The mains-frequency is 2-poles low-pass filtered ($f_{cuttoff}$ = 75Hz) using an active Sallen-Key filter. A 'zero-cross' detector converts the filtered sinewave to 'digital pulses'. With use of the Timer/Counter peripheral within a cheap microcontroller this signal is gated with the 32.678 kHz pulses of the accurate RTC chip. The number of pulses counted represents the mains-frequency. The process is repeated 200 time and averaged. Total time to determine mains-frequency is about 4 seconds.

Figure 13 shows the total system of measuring the mains frequency.

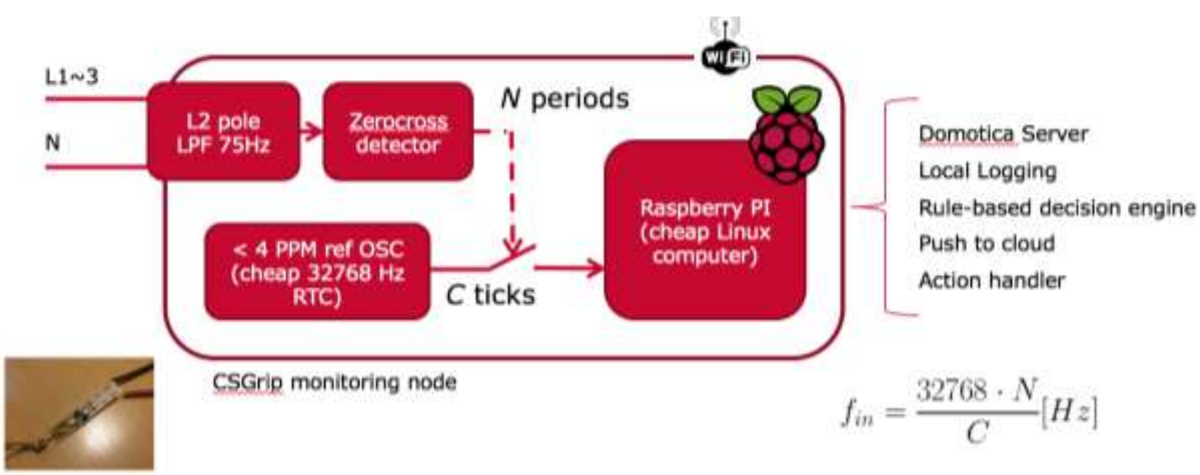


Figure 13: frequency measurement system including home automation

During approx. 160 test cycles the mains frequency was measured. (It appears that the mains frequency was less than 50Hz during the test). Measurement results are within the 0.1Hz accuracy with respect to the mean.

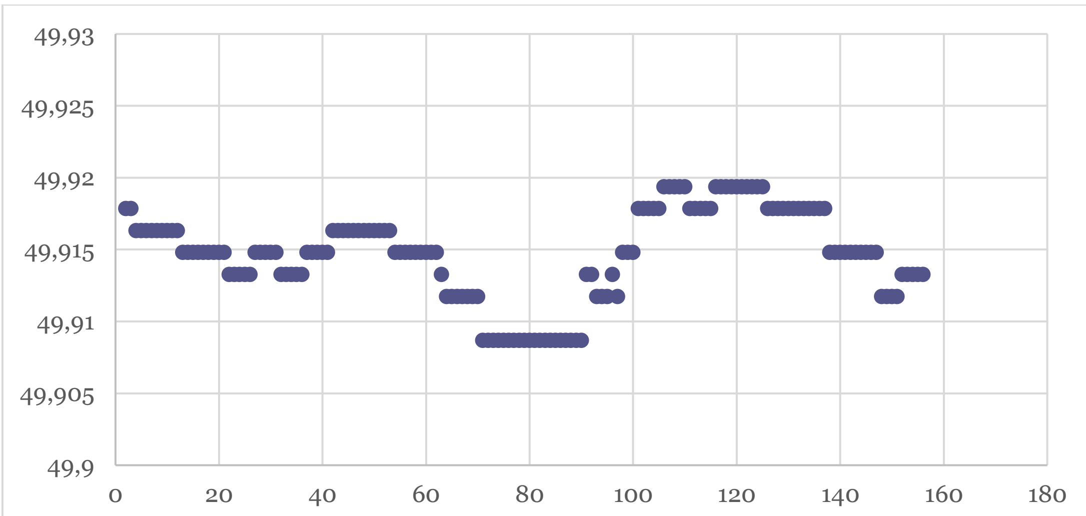


Figure 14: frequency accuracy measurements

Using the Maxim DS3231 RTC, measuring mains-frequency can be performed with accuracy < 0.1Hz and within a 10 seconds interval. To improve the accuracy more effort in input signal noise reduction and phase error correction is needed. This means better performance of the LPF filter and the zero-cross detector.

The mains frequency is an input to the load balancing algorithm. This algorithm is implemented in a home automation subsystem (using graphical tooling and a bit op Python). Both subsystem use the MQTT message broker services (on top of TCP) for communications.

Figure 15: home automation open software platform

Frequency is an important variable because it gives information about the stability of an AC voltage grid. Power plants must always deliver the required amount of power to the network. If more power is used frequency decreases. At excessively high feed or low power, the frequency increases. To control the balance between consumed and produced power, three main control stages are used. They are the primary, secondary, and tertiary control stages. Without these mechanisms, the network would collapse.

The dissucced setup has been tested with the HAN CSGRIP demonstrator as described in chapter one. Figure 16 shows the used test set-up.

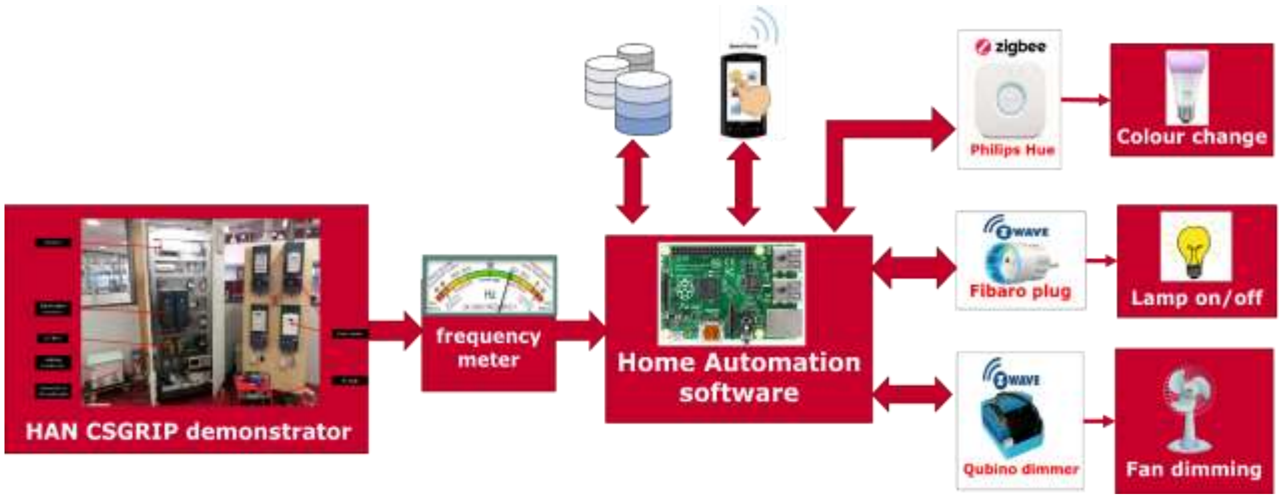


Figure 16: home automation test set-up

The following control strategies as developed within CSGRIP project have been programmed in the home automation system:

1. Options 1: Hue lamp to change colors based on power consumption or mains frequency
2. Option 2: on/off switch of (Hue) lamp, fan, motor, and heater
3. Option 3: dimming lamp, heater on lower power, fan on lower rpm

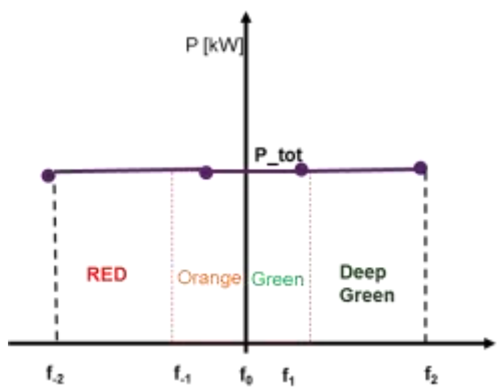


Figure 17: Informative: changes in the color of the light

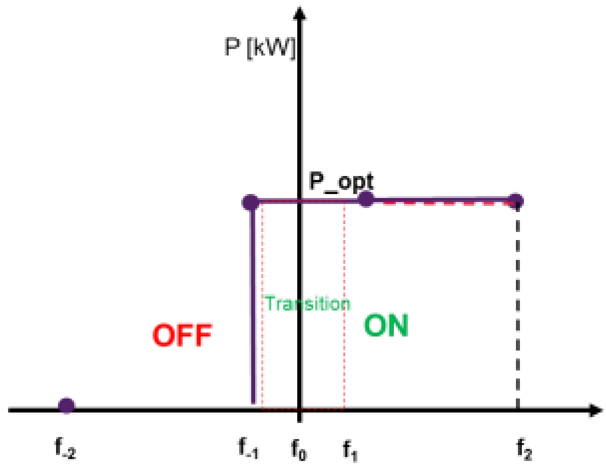


Figure 18: ON-OFF Control

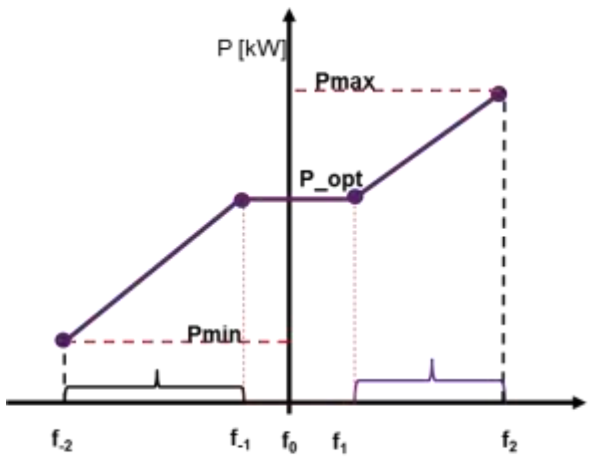


Figure 19: Adaptive control: changes power consumption

Test results:

The frequency of the HAN CSGRIP demonstrator has been changed from 48Hz to 52Hz in steps of 0,1HZ. Below the obtained results for two frequencies resp. 48Hz and 52Hz.

Frequency is 48Hz	**Frequency is 52Hz**
 HAN CSGRIP demonstrator frequency: 48Hz	 HAN CSGRIP demonstrator frequency: 52Hz
 - Measured frequency with Fluke meter is 48Hz - Measured frequency with Avans freq. meter: 48Hz (see user interface in laptop screen) - Hue lamp is red, incandenscent lamp and fan are off	 - Measured frequency with Fluke meter is 52Hz - Measured frequency with Avans freq. meter: 52Hz (see user interface in laptop screen) - Hue lamp is white, incandenscent lamp and fan are on, full power
 - Hue lamp is red, incandenscent lamp and fan are off	 - Hue lamp is white, incandenscent lamp and fan are on, full power

Figure 20: test results home automation set-up with HAN CSGRIP demonstrator

Additional to the tests described above a home automation demonstrator case has been built with different exciting home automation components and communication protocols. The cheap components based on RF communication as well the more expensive components based on Z-wave communication have been used. The home automation set-up is universal, flexible and modular which make it easy to include other future developed home automation components. Also a smart meter and other sensors like motion and temperature can easily be included. The schematic of the built home automation demo-case is shown in figure 21.

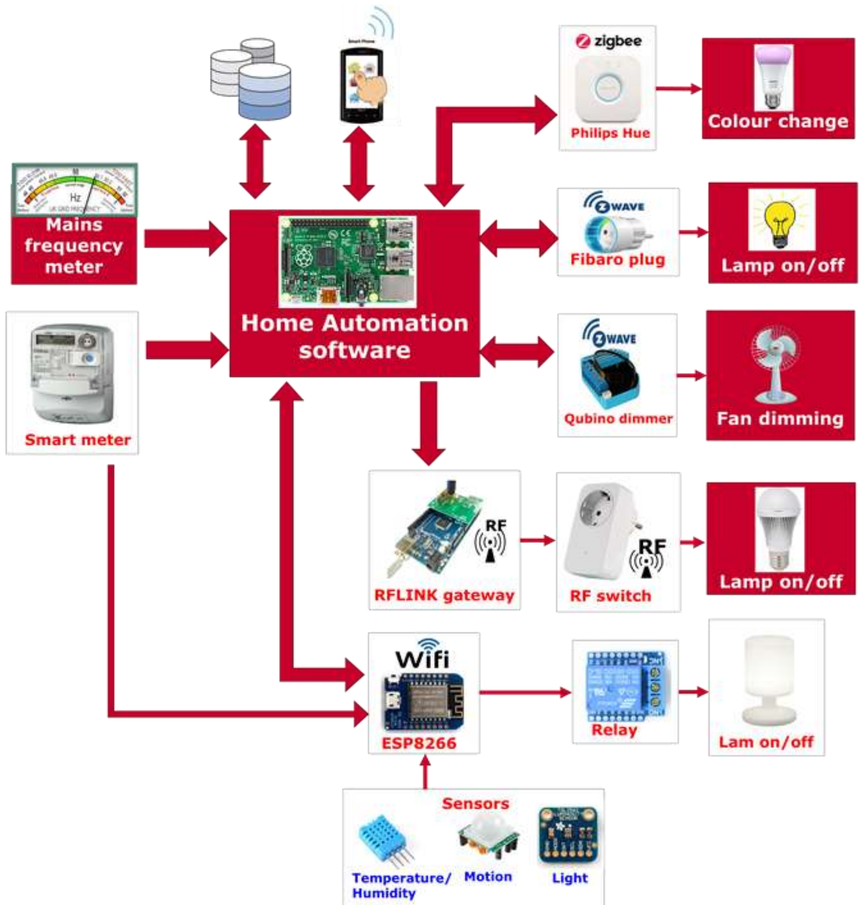


Figure 21: schematic of the home automation demonstrator case

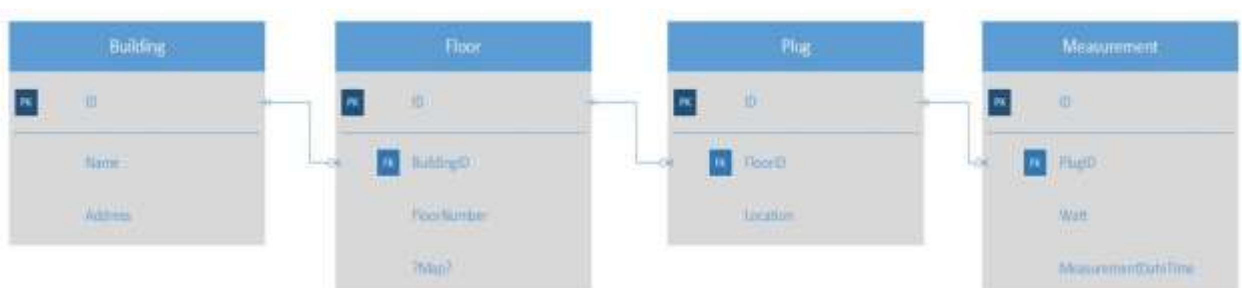
Figure 22 shows the developed home automation demonstrator case,

Figure 22: home automation demo-case

4.5 Monitoring of user experience test set-up (D4.4)

Building the Domoticz application

Using a Raspberry PI V3, a RaZberry Z-Wave interface and a few Fibaro Plugs a home automation application test environment have been built. Using standard Linux scripting tools Fibaro Plug data is collected and stored in a database. This data is made available using RestFul API's.



Below the lessons learned:

The open source Domoticz application in conjunction with RaZberry Z-Wave hardware turned out to function stable. Connections with the Fibaro Plugs is not always reliable, probably due to 868MHz signal interferences in the Avans building and long distance between receivers and transmitters. Plugs do automatically reconnect after loss of connection. The Raspberry PI V3 system has proven to be reliable when powered by a good quality power supply

User interaction is needed to install (new) plugs. This process needs improvement (user interaction).

Building an energy monitoring app for Android and IOS

Based on mobile application development techniques the data made available from the Domoticz application is used to display ‘power graphs and -heatmaps’.

Below the lessons learned from building an energy monitoring app:

Generating heatmaps turned out to be difficult to create. This will need further attentions. It is not difficult to design and build mobile apps to display data (graphs).

5. Conclusion

The demonstration setups provided useful data and control strategy to test CSGriP functions. The HAN demonstrator was suitable to test a stand-alone CSGriP cell as well as grid-connected cell. The parameters for the power-frequency drooping were tested and control strategies for island and grid-connected modes were verified.

On the demand side control, smart electric vehicle charging unit functioned based on the system frequency, charging more when frequency is higher than a set threshold and charging with less power when frequency goes below a minimum threshold. The smart meters, on the other hand, were tested to switch ON/OFF to control the energy demand using the system frequency. The results showed that given the accurate parameter settings, the smart meters functioned as expected.

The Home Automation (HA) system was developed using low-cost technology to accurately determine accurate mains frequency. Based on the measured frequency value, three different colors, were used to indicate periods of less, enough, and excess energy availability.

Furthermore, user behavior as a control for demand-side management were implemented. The indicators provide consumers information to take action on their energy consumption – consume less, stay the same, or consume more.

Finally, the connected household load were controlled based on a rule-based engine in a modern, open source home automation platform. Devices either switched ON/OFF, or increased/reduced their power consumption based on the system frequency.