A Challenge from Sweden

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IEM Test and Verification Final Report

Part B: Results

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Published in May 2018 by Sustainable Innovation Sweden AB

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Contents

1 Background.. 4
2 Evaluation of the IEM solutions 5
2.1 Description of the evaluated solutions 5
2.2 Evaluation strategy 7
2.3 Evaluation criteria 9
3 Test & verification (summary of the report, Appendix 1)... 11
3.1 Ferroamp 12
3.2 Amzur Technologies 16
3.3 Certh 18
3.4 INNOENERGY 21
4 Evaluation of Business criteria and Organisation... 25
4.1 Ferroamp 25
4.2 Amzur Technologies 27
4.3 Certh 29
4.4 INNOENERGY 30
4.5 The ability to provide flexibility in the system 31
5 Complementing analyses 32
5.1 Marketing prerequisites for IEM systems 32
5.2 The market development for electric energy storage in real estate applications (Appendix 2). 32
5.3 Survey of market prerequisites for IEM system solutions (Appendix 3).................. 33
5.4 Obstacles in development of sustainable local energy systems (Appendix 4) 34
5.5 Needs analysis, results from inquiry, April 2018, (Appendix 5). 35
6 Discussion and conclusions 36
6.1 Software, hardware, or system solution 36
6.2 The integrator role... 36
6.3 Market introduction 36
6.4 Matching of system solutions and stakeholders 36
6.5 Technology, resources and dialogue affects the time schedule 37
6.6 Factors to weigh in during pilot installations 37

6.7 The sunlight exposure's effect on the time schedules ... 37
6.8 Technology ... 38
6.9 Discussions about the market development for IEM solutions ... 42

Appendixes (Swedish only)

Appendix 1 - Test & evaluation of system solutions in the pilot project IEM

Appendix 2 - Market development for energy storage in building applications

Appendix 3 - Survey of market prerequisites for IEM system solutions

Appendix 4 - Obstacles in development of sustainable local energy systems

Appendix 5 - Needs analysis, survey results, April 2018.

1 Background

The Swedish Energy Agency and Swedish Incubators & Science Parks (SISP) commenced the IEM venture in 2015. The purpose was to seek new energy system solutions for buildings producing solar energy. The solutions will entail that a larger amount of the solar energy production is used in the building where it is produced, e.g. trough storage and directing the energy usage to times when more solar energy is produced. The energy systems of the future may need more storage and flexibility, since the amount of produced renewable energy is increasing.

In the phase “Defining needs” a collaboration with five stakeholders was established. Their needs were described as connected to installations at their disposal or that they planned:

- Arvika Municipality/Glava Energy Center (solar cell park and test area in Glava for solar cell installations/battery storage etc.)
- Eskilstuna Municipality (school building)
- Riksbyggen/Göteborg Energi (planned residential building, 120 apartments)
- Ihus - Vaksala Eke (industrial building in Uppsala)
- Herrljunga Bostäder (planned small house area, around 15 households)

In the next phase, “Market dialogue”, an international innovation competition, ”Intelligent Energy Management Challenge”, was carried out in collaboration with the organisation Nine Sigma. After an evaluation in several steps the competition was concluded in the beginning of 2016, when four winners who were qualified for the next phase, “Test/verification” were chosen. The winners were:

- CERTH (Centre for Research & Technology, Hellas), Greece.
- Amzur Technologies, USA.
- Innoenergy, Sweden.
- Ferroamp Elektronik, Sweden.

To carry out the Test/verification phase, SISP chose to engage Sustainable Innovation. An order with a commission specification was drafted in cooperation with the Swedish Energy Agency.

2 EVALUATION OF THE IEM SOLUTIONS

2.1 DESCRIPTION OF THE EVALUATED SOLUTIONS

2.1.1 AMZUR TECNOLOGIES

Amzur Technologies has developed a smart energy meter, anticipating battery consumption and the generated solar power. The energy meter can help the user to choose when it is time to charge the battery and when it is time to buy electric power from the power grid. The system is built on the comprehensive software Microgrid Energy Management Systems (MEMS), which is connected to the building's/buildings' existing SCADA system for controlling PV cells, battery storage, electric car charging, etc. as well as load control and switching between external/internal nets.

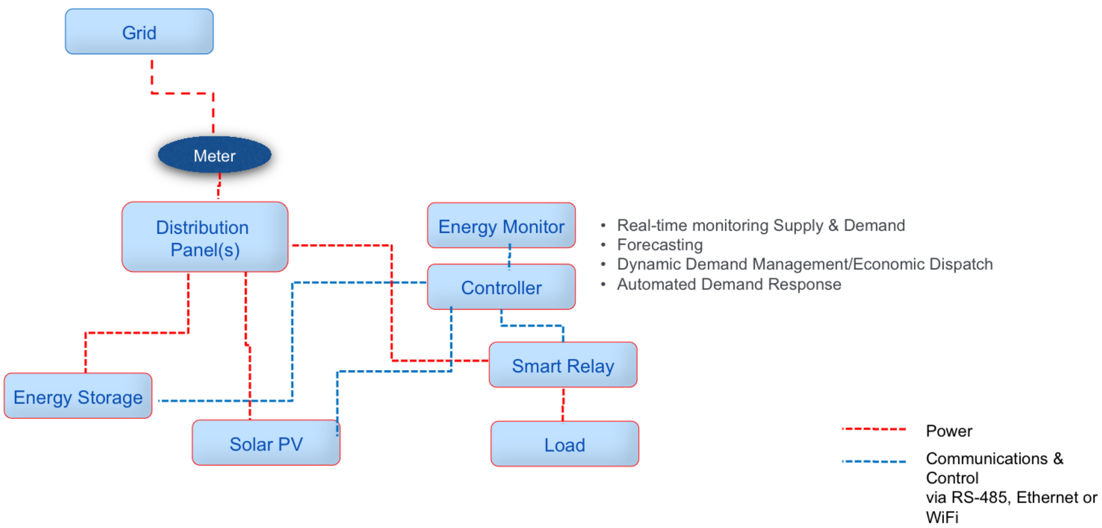


Figure 1. System sketch, Amzur Technologies

2.1.2 CERTH

CERTH has developed the self-learning energy system Equilly, which adapts after several key factors and becomes better at taking smart decisions for the building's energy consumption in real time. The system is built on the comprehensive control and surveillance software Equilly, which is connected to the building's/buildings' existing system for real estate automation to control PV cells, battery storage, electric car charging, etc. as well as load control and switching between external/internal electric nets.

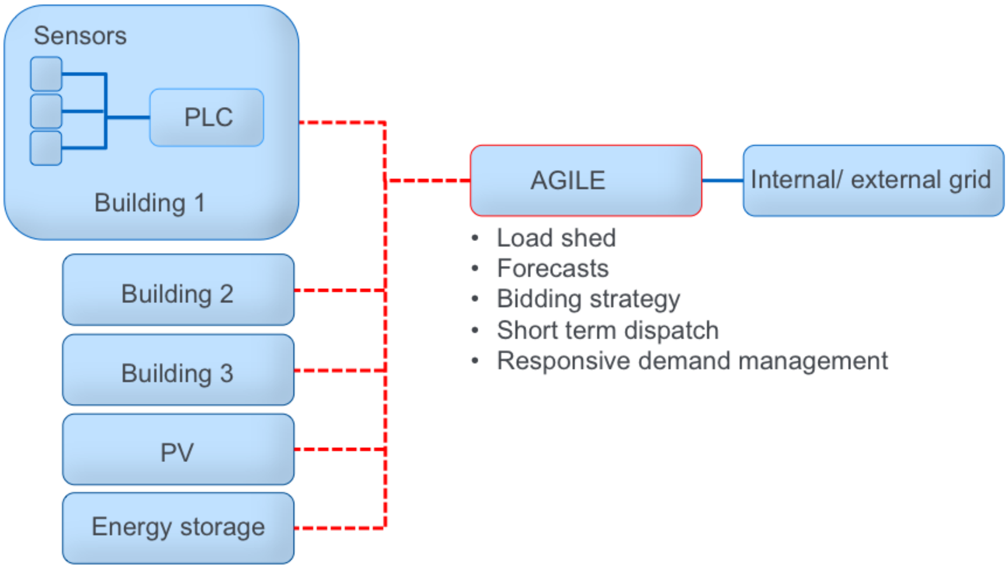
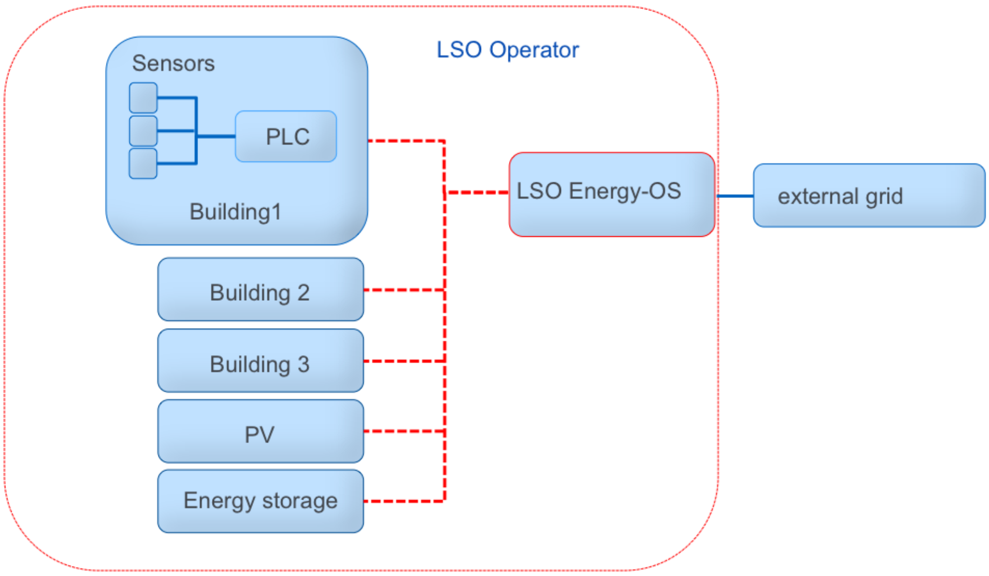


Figure 2. System sketch, Certh (AGILE = the software Equilly)

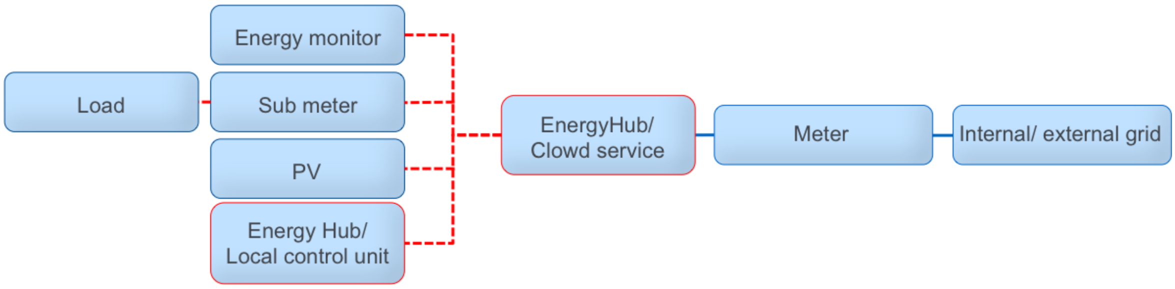
2.1.3 INNOENERGY

InnoEnergy's solution, Local System Operator (LSO) has developed a business model for smarter energy usage through an innovative business model, built on local production and consumption. LSO is based on an integrated platform of chosen energy solutions from InnoEnergy's large network of partners and start-ups.



2.1.4 FERROAMP ELEKTRONIK

EnergyHub is a scalable system solution, easy to integrate in the network, resulting in more efficient energy management, less waste heat, simpler installation, and easier maintenance for the users. The system is built on the comprehensive control and surveillance cloud service EnergyHub, which is connected to the building for controlling PV cells, battery storage, electric car charging, etc. as well as load control and switching between external/internal nets.



2.2 Evaluation strategy

2.2.1 Structure of the test sites

Of the four chosen system solutions, three consisted of software, (Amzur, Certh, and Ferroamp), and cloud services for control of local energy systems. The hardware was generic for Amzur and Certh, but Ferroamp had a product of their own in their energy storage. The fourth solution, (InnoEnergy), was a business model, that could advantageously be applied to the other solution proposals. In discussions with the system suppliers, it was revealed that InnoEnergy already had begun the development in cooperation with Ferroamp, and therefore wanted to focus their actions in a common test site with them. Due to the above, the test sites were structured by carrying out three test sites, with one in two hierarchical levels Iincluding both Ferromap and InnoEnergy).

2.2.2 The selection of test sites and matching to system solutions

In common with the stakeholders, the project group set the time schedule as well as the criteria below, for the matching of potential test sites and system solutions.

The users' sensitivity for disturbances

The system solutions were regarded to be in different phases of maturation. This being said, certain systems were expected to render more disturbances than others during the test site phase. Thus, it was important that the test sites where selected with regard to the users who lived, worked, and managed the test sites, to achieve minimal disturbance.

Already installed/proven system solutions

The system suppliers had, at the time of the test, reached different levels in their market introduction. The ones who had reached the farthest already had several more or less commercial installations that easily could be supplemented to function as complete test sites in IEM. The systems that were the farthest from a market introduction had yet only been tested in laboratory environments, which was taken into consideration in the choice of test site installation.

The process for selection and matching

The stakeholders were invited by the project to define the characteristics of the test sites which were offered to the project's test/verification phase. Then the project group added alternate test sites which complied with these criteria. The stakeholders and the suppliers then prioritised and gave their opinions on the choice of test sites.

The test sites relevance for the stakeholders

The selection of test sites was related to the project's comprehensive issues, prioritised issues from different groups of interested parties, as well as within which parts of the collected test environment these issues could be solved. Stemming from this work, a selection of test sites was made, to best meet the project's time schedule and the prioritisation of all interested parties, where each could be connected to a system solution, as explained below. The test sites where divided in priority 1 and 2, where 2 was an option in case priority 1 could not be carried out, or if the project decided to carry out more test sites. Both installations listed under priority 2 were considered as advantageous for engagement in the project's Living Lab.

Priority 1

Glava Energy Center 1, Arvika

The building had a 350V direct current system (DC), with energy storage installed, run by 8 kW solar cells, installed on the roof. The system was connected to the power grid when the solar energy production/the batteries weren't enough. The DC system included a ventilation system, LED lamps, and fridge/freezer. The batteries had two charging programs for spring/summer/autumn, and winter.

Selected system supplier: Amzur

Slagstaskolan/Eskilstuna

Since 2014, the Slagstaskolan school had a system with solar energy on the roof, that delivered 85 kWp. Data collection through Mbus and RS485 for energy production and measurement data was being installed at the time. The area included 5,100 square metres. The electricity consumption per year was around 260 MWh, with a minimum value of 7-8 kWh under load in July. The installation had no energy storage and was by then considered to need a supplement in the form of charging for electric vehicles.

Selected system supplier: Certh

Ihus/ Vaksala Eke

At the time, Vaksala Eke was an industrial area in Uppsala with two buildings (A, B). Building A (3,600 sq. m.) included solar cells, delivering 10.8 kWp with a battery storage of 20 kWh with a possible UPS configuration. Building B (1,800 sq. m.) included solar cells on the façade, delivering 11 kWp, and included 6 charging posts for electric vehicle charging. In addition, Vaksala Eke had an interest to investigate if a direct current net between the installations in the area could increase the self-consumption of solar energy, level phases, as well as reduce peak loads.

Selected system supplier: InnoEnergy/ Ferroamp

Ihus/ Salagatan

As a complement to the installation in Vaksala Eke, Ihus put their office on Salagatan 18 at the test's disposal. Salagatan 18 had an installed 10 kWp solar cell installation. To increase the self-consumption of produced electricity, the supplier was to install an energy control system, including energy storage, complete with an energy storage module.

Selected system supplier: KIC InnoEnergy/ Ferroamp

Priority 2

HSB Living Lab

HSB Living Lab is an apartment building with 29 apartments in Göteborg. The façade of the building was to be equipped with 5-10 kWp integrated solar cells in 2016. It was also possible to install a battery storage and charging of electric vehicles. The HSB Living Lab project is a collaboration between 12 organisations within sustainable living. The building, situated on Campus at Chalmers University of Technology, will be used as a platform for FOU projects for ten years.

Örebrobostäder

At the time of the test there was a potential test site or Living Lab in one or more of Örebrobostäder's apartment buildings. The system suppliers Ferroamp/InnoEnergy had a working relation with Örebrobostäder, which meant that a test site could be put up without delay.

Arvika Municipality

A potential test site in Arvika Municipality, for an upgrade of engine preheater connections with control systems and energy storage for recharging the chargeable cars in the municipality, was possible to develop.

2.3 Evaluation criteria

The project group, in consultation with the stakeholders and the system suppliers, created a gross list with prioritised evaluation criteria.

The criteria were divided into the categories below: Stakeholders and system owners were united in their appraisal of these evaluation criteria, and all criteria were highly prioritised.

Organisation

To create understanding of the organisation's capacity to commercialise the product and breakthrough on the market, the organisations staff and financial resources were appraised.

Business criteria

By the same reason as above, the business criteria were evaluated to analyse the organisation's potential for a breakthrough on the market. This category evaluated the business model, scalability, financing, strategy, patent/IP, ability for technology leaps, competition, and how legislative changes could affect the business model.

User friendliness

The requirements of the system solution on the users (residents, maintenance and management staff) and the capacity of the solutions, as well as time for self-learning, were evaluated under this criterion. The user friendliness was to be studied further under the planned Living Lab activity.

Technology

The technology section focused on the technical functionality, stability, and quality of the system.

Security

The security criterion included how the solution was constructed to minimise the security risks, but also the warranties, upgrading, and surveillance options the system had, and how the solution maintained a good electricity quality and electricity security.

Sustainability

The sustainability criteria were widely stated, with the purpose of analysing the system's life cycle through manufacturing/running/re-utilisation/recycling, as well as the degree of self-catering.

Open Data

Finally, the system solution's openness in the communication interface, its plug-and-play level, and the possibility to manage open data connections to other solutions and third parties.

3 Test & verification (summary of the report, Appendix 1)

The presented evaluation of the systems' technology, tests, and results was performed by Hannes Hagmar and Maria Hammarquist, RISE. In an amendment to this evaluation, Sustainable Innovation has evaluated the systems' User friendliness, Sustainability, and Open Data. A summary of this evaluation follows below. The complete evaluation can be found in Appendix 1.

Comment on how to perform quantitative evaluatation of the technical aspects of the system solutions

Quantitative estimation of the system solutions, and above all, of the increased efficiency, requires that the estimation is made relative to some form of reference. The reference can either be a reference facility, or the efficiency or functionality before installing the system solution. For some parameters, the quantitative estimation has not been possible, since the development of a method and the determination of a reference was not included in the project.

The parameter of this project which was not fully investigated, is how much the system solution has contributed to the increase in self-consumption. Why is explained below.

Verifying that a change in the control system does result in higher self-consumption of solar energy, like for example storage and control of energy use and battery levels, and in addition quantifying this increase requires advanced methodology:

The correct way to ensure change in self-consumption would be to use a standardized test bed, with controlled load and controlled production conditions, to run a test with and a test without the control algorithm. However, objections can still be raised against this methodology; for example, how well does the applied load and production conditions reflect the reality?

For practical installations, data before and after installation could in theory be compared - first the system is run without intelligent control during for example one year, then it is run with intelligent battery control for one year, and then the data is compared. Especially over time, trends will be obtained that should give a good idea of the self-consumption rate. An approximate view can be obtained, because the comparison is not quite correct since both the load situation and production conditions (solar radiation) will vary. The disadvantage is also that this takes time.

It is also possible that the manufacturer includes the evaluation in the algorithm by adding a parallel calculation of what the situation would have been like without the control system; IF there was no battery pack all surplus energy would instead be exported, so how much energy is stored? IF we have these predictions, we will make the following choices for load control, (alternatively to what level the battery is charged) - what choices would we have made without the control system and how high had the self-consumption been then? However, this would complicate already complex programming. Of course, there is already some form of evaluation, since that is how an adjustment and optimization of the system is made. However, to estimate these selections by reverse engineering from measurement data and then quantify the impact on self-consumption, still yields dubious results, as full transparency regarding the choices of the algorithm can hardly be achieved simply by examining the measurement results.

One might also consider the cost development, alternatively the imported and the produced power respectively and their mutual relationships (as most commercial users nevertheless do), but also this requires pre and post data with the accompanying memento that the measurement situation is not exactly similar. However, for a user logging a system for a long time, and then performing a change or completion of the system, differences in self-consumption should be detectable in this way. Common to all these methods, however, is that they require a time period of at least one year, to avoid too large errors due to seasonal variations.

One conclusion of this project is: The development of a standardized method for accurate and traceable evaluation of the increase in self-consumption is desirable as it would increase the comparability of different system solutions, thus facilitating rational decisions by financiers, developers, decision makers and users.

3.1 Ferroamp

3.1.1 User friendliness

The installation of the pilot turned out relatively easy for Ferroamp, except for the fact that the hardware deliveries were delayed. The company feels mature in its way of working and has routines and resources for the installation process. In addition, the support to the installation engineer went well. Although the feedback after completed installation has been lacking, and an introduction and documentation for using the system is also missing. Ihus' technicians have not received a walk-through of the system and therefore are not able to do anything more than superficial error controls in the system.

3.1.2 Technology

Only one participant, Ferroamp, delivers a complete system with both hardware and software. The advantages of the system are many, for example, minimizing internal power loss, overall coordination of consumption, storage and production the and possibility to expand the system with, for example charging of electrical cars, with associated possibilities for power optimization and cost-efficiency.

Ferroamp's system is genuinely scalable and minimizes internal power losses by having a local DC-grid and a single, centrally located, bi-directional converter called the EnergyHub. The control system also communicates with high-resolution electricity meters and sensors located at loads, PV system, and on incoming power lines. Calculated values are sent to the cloud service. Through advanced algorithms and pre-determined settings, the EnergyHub regulates and controls energy flows between solar panels, energy storage systems and power grid.

There is an integrated system for equalizing the magnitude between phase currents (phase equalization). The system protects from overloading of fuses in the presence of large current asymmetries, and often buildings can reduce fuse size and thus save money. There is also a proprietary energy storage system controlled by an integrated battery monitoring system to maintain temperature, check charging cycles and optimize battery cells. Additional separate systems, even with varying voltage levels, can be integrated.

A proprietary Solar String Optimizer that controls and maximizes the efficiency of solar panels is also offered. All components communicate with and are controlled by the EnergyHub and can be remote controlled. Based on characteristics of load patterns, power peaks and possible PV production, the system is adapted. The system is currently calibrated and adjusted for optimal load control. Below is a summary according to the bullet list in the method section on page 7 in Appendix 1.

Analyzed parameters – Ferroamp	
When does the control system choose to start discharging the energy storage? Are these decisions based on previously obtained measurement data? Is the system adaptive and can it handle changes in load and production? Does the system handle differences in load and production between different days (weekdays/weekends)? Is weather data used to forecast PV production and thus control the energy storage?	The energy storage is charged when there is an overproduction of solar power or from the grid, based on historical characteristics of load patterns, power peaks and possible production from photovoltaic installations. The system is adaptive and can handle changes in load and production, over which time horizons cannot be commented based on available data. The control system is not adapted based on weather forecasts.
How well is the energy storage able to handle power peaks? How large margins does the control system have to handle load variations? How is the wear of the energy storage minimized?	The size of the energy storage is 7.2 kWh, and by not allowing the state-of-charge to drop below for example 40%, there is always a margin to handle peaks and variations of 2.88 kWh. Wear of energy storage is minimized by ensuring that the energy storage is not discharged below a predetermined level.
If load shedding is active, how does the control system choose to control the loads? At what times? Is weather data used to create an adaptive system? Can users control the load shedding themselves?	Load shedding has been active during the whole test period. The system's flexibility in managing and controlling both the internal and external variables, central conversion that minimizes internal losses and adaptive phase equalization, gives a system competent for load management. The current instance of the system does not use weather forecasts or instantaneous electricity prices to create an adaptive system. The system can allow user control of the load shedding, but this function was not applicable for the current installation.
When is the energy storage charged? Can it be adjusted for charging at times of low load or low electricity prices?	The current instance of the system does not use instantaneous electricity prices to charge the energy storage at low-priced rates. The energy storage is charged when there is an excess of produced PV-energy in relation to consumption or from the

	electricity grid.
During a sunny day of high PV production, how well does the system succeed in increasing self-consumption of solar energy?	It is not possible to indicate how much the self-consumption increases due to the control system, since the collection of measurement data before and after installation of the algorithm, corrected for variation in load and consumption patterns was not collected within the scope of this project. See also the introduction in Chapter 3. However, a minimum level of self-consumption increase is obtained from the size of the energy storage. During summers, power flows are controlled so that the energy storage is always fully charged in the evening, when the PV system is no longer delivering power. This gives a minimum level of self-consumption increase of 7.2 kWh, which is the capacity of the battery storage.

3.1.3 Security

Ferroamp's products are largely based on scalability where more devices can be added with changing needs. The EnergyHub system is adapted for use at all types of effect levels, where more modules can be added to the system until the efficiency capacity needs are achieved. Wall-mounted covers and rack cabinets are adapted for efficient storage of different sized systems.

The energy storage is scalable as well, where each device has a capacity of 7.2 kWh. The output voltage for each battery system is controlled, to keep the same level as the DC link voltage. Thus, several batteries of different ages and charge levels may be used in one system. It is possible to use other battery systems than Ferroamp's own, as long as these meet the voltage requirements for the DC link and include a battery surveillance system.

Remote control and operation

Through the developed cloud service and web portal, the users get direct insight into their own consumption patterns, as well as the system functionality. Since the system is connected, the users can access the functionality wherever they are.

Previously software and changes required manual updates, where the staff had to enter the updates manually into the EnergyHub. During the project, development of a new platform, Yocto, has commenced, to directly connect the components to a secure server to facilitate remote updates, troubleshooting, and log checks. Today, the Yocto platform is almost completely implemented in all systems. Around 400 systems are installed, where updates still remain for the last 10%. In some cases, they are not connected to the Internet, and in other cases they require a physical presence due to other reasons. The implementation is not required for functionality, but since this is the new platform, these systems won't be able to update if the not get the new platform. Yocto means a lot for further development of the system, since it frees resources and simplifies the management of system settings. The data transfer is performed through an SSH protocol, where all data is encrypted to perform the connection securely.

Protection and security

The LiFePO4 technology, used in Ferroamp's energy storage Smart Energy Storage, has a significantly higher thermal and chemical stability in general, than other types of lithium-Ion batteries, entailing improved security for any short circuits or overloads. In addition, Ferroamp has developed a battery surveillance system, used for concurrent surveillance of each separate battery cell in the energy storage system, where voltages and discharges are balanced for improved useful life and security. To the system, relays can be added to protect and disconnect the energy storage system if abnormal operations are detected.

Another security system is built between solar string optimisers and the EnergyHub. The control device is directly connected to the EnergyHub and can be remotely turned on and off. The control device requires constant communication with the EnergyHub and if any errors or accidents occur, the control unit will be shut down automatically for increased security. If several EnergyHubs are connected to the same system, there will be some redundancy, since parts of the production can be maintained even if a single module breaks down. In addition, there is a proprietary fire protection, called Fireman Switch, that is used to directly disconnect the solar electricity installation in case of fire.

3.1.4 Sustainability

Re-cycling of Ferroamp's products are performed according to the current standards for electronic equipment. The products are stripped down and recycled. From the circuit cards, vital components are dismounted, and the other parts of the circuit card goes through a recycling process. The company is required to reclaim the batteries for recycling after finished "service".

Ferroamp has not performed an LCA analysis, but it can be said in Ferroamp's favour that:

1. That the number of converters between AC/DC are decreasing since one converter can manage several functions (production, storage, charge).

2. With common DC nets conversions and losses are reduced further.

3. With these systems the power output is reduced, which reduces the need for new investments successively.

3.1.5 Open Data

Ferroamp's system is based on their own integration of all functions for the building in their system solutions. Though the company sees installation engineers and system integrators as their future sales channel, which opens for combinations with other suppliers as well. To this effect, Ferroamp offers streaming data for communication with other systems and comprising control and measurement systems through API and Modbus TCP.

3.2 AMZUR TECHNOLOGIES

3.2.1 USER FRIENDLINESS

It stands clear that Amzur comes from the software sector, and not from the energy sector. The elegance of the system is their open source code and cloud-based services. This has potential for distribution.

Amzur use Intel NUC standard PCs with Linux dialect and direct current meters connecting them, which should facilitate distribution at large. Neither the staff of GLAVA nor Amzur had worked previously with direct current meters in combination with these systems, which created some problems when taking them into service.

The installation took a long time but did not involve a lot of factual extra work. The engaged electrician lacked computer competence, which entailed that the installation went a little slower than usual. Magnus Nilsson at Glava is convinced that the installation can achieve a good plug-and-play level if:

- Amzur packages and specifies the required hardware and installation better. A suggestion would be for Amzur to package and sell hardware, where they can guarantee the functionality. (Like Norwegian Eltek, which they contacted during the trade fair in May.)
- Amzur is establishing a network with knowledgeable integration companies.
- The engaged installation engineers have data communication skills.

3.2.2 TECHNOLOGY

Amzur uses Linux and is based on open source code and has also developed the design for the communication and control systems for energy measurement, load management and battery control for the current pilot site. Below is a summary according to the bullet list in the method section on page 7 in Appendix 1

Analyzed parameters – Amzur	
When does the control system choose to start discharging the energy storage? Are these decisions based on previously obtained measurement data? Is the system adaptive and can it handle changes in load and production? Does the system handle differences in load and production between different days (weekdays/weekends)? Is weather data used to forecast PV production and thus control the energy storage?	The current site cannot export energy to the grid, so the charge of the energy storage always occurs when PV production exceeds consumption. The system itself is adaptive and can handle changes in load and production, but since the consumption situation in the current site is uncomplicated, the more advanced features of the algorithm are not utilized. Thus, self-consumption and storage maximization has natural high priority in the algorithm. The charging and discharging cycle of the battery is based on available forecasts for load and solar power generation, based for instance

	on weather data.
How well is the energy storage able to handle power peaks? How large margins does the control system have to handle load variations? How is the wear of the energy storage minimized?	Peak shaving has a high priority in the algorithm and is based on user-defined parameters. The capacity of the energy storage is 3.5 kWh and by not allowing the state-of-charge to drop below for example 40%, there is always a margin to handle peaks and load variation of 1.4 kWh. Minimization of battery wear is prioritized, using previously mentioned prediction-based control of charging and discharging cycles.
If load shedding is active, how does the control system choose to control the loads? At what times? Is weather data used to create an adaptive system? Can users control the load shedding themselves?	Advanced optimization with for example machine learning did not prove fruitful given the pilot's fairly simple consumption pattern. The user can control the load control parameters, and the system allows temporary changes to the load management schedule.
When is the energy storage charged? Can it be adjusted for charging at times of low load or low electricity prices?	This feature can easily be implemented in the algorithm but was not included in the specified requirements for the current site.
During a sunny day of high PV production, how well does the system succeed in increasing self-consumption of solar energy?	To give an idea of the increase of self-consumption due to their algorithm, Amzur has compared the self-consumption during one month without the algorithm and one month utilizing the algorithm. One month is a short time for such an evaluation but it still gives an indication. In addition, loads and production were reasonably similar during the two months compared. During these two months, self-consumption increased from 36.7% to 58%, i.e. by 21.3%. These data have been obtained from Amzur, since the evaluation was made Amzur after the project was reported.

Amzur is assessed to have completed its installation and commissioning of the current site.

3.2.3 SECURITY

Since the developed control system uses an ordinary, so-called “off-the-shelf” computer, the upgrade and surveillance possibilities are very good. When the needs are changing in the future this entails that hardware (for example modern energy production, more storage, and new types of loads) as well as software can be updated or replaced without major infringements in the operation. Remote upgrades are possible. An available modem with internet connection is sufficient to make remote surveillance and operation possible. All software functions may be performed remotely, and any warnings and alarms will be communicated to the operational manager.

The cloud-based monitoring application manages and, if needed, redirects system alarms and system information to the relevant recipient, e.g. by direct messages and e-mail. The user may control the triggers and events, (e.g. Interruptions in the communication or abnormal data), that may generate an alarm or information messages. The user may also analyse generating, storage, load, and type of load by day, month or year, and may download data for further processing in spreadsheet format.

3.2.4 Sustainability

Amzur is completely independent on hardware and has no requirement on these parts.

3.2.5 Open Data

OpenDEM is based on open source code and meets open standards, including IEEE2030.5 Smart Energy Profile (SEP2) and ASHRAE Facility Smart Grid Information Model (FSGIM). Amzur is currently integrating Open Field Message Bus (OpenFMB). The software, the API, and the technology stack are all open source.

3.3 Certh

3.3.1 User friendliness

The installation and taking the pilot into operation has suffered several problems, that must be solved before a market introduction.

The integration of software and the existing installation's system/products rendered problems, in this case the freezer, kept by Slagstaskolan. WSP had initially done their homework badly and suggested a solution that did not work. The same applied to the information from Certh, about the required platform for the software installation. Due to this the municipality was forced to change computer from a 32-bit environment to the 64-bit environment required by Certh's software. To take the installation into operation Certh has rewritten the software with a special application. This must be changed when upscaling, to configuration files outside the software, otherwise the maintenance of all these special applications will be unmanageable.

The need for engaging a skilled integrator is large, but also to get good instructions for customers and installation engineers. These were lacking during the installation of the pilot, which resulted in the procured electric installation company having difficulties making the system operational.

Finally, it may be pointed out that a good dialogue and communication is important. As it is, language and geographical distance creates a problem which entails that Certh must take the system into operation on site to make it work.

3.3.2 Technology

Certh's algorithm uses real-time measurements from the PV system, energy storage and power consumption, and then controls the micro grid to optimize the control strategy. Certh is currently working on optimizing its algorithms for optimal load management involving machine learning and is assessed not to have completed the everything in this project. Below is a summary according to the bullet list in the method section on page 7 in Appendix 1.

Analyzed parameters – Certh	
When does the control system choose to start discharging the energy storage? Are these decisions based on previously obtained measurement data? Is the system adaptive and can it handle changes in load and production? Does the system handle differences in load and production between different days (weekdays/weekends)? Is weather data used to forecast PV production and thus control the energy storage?	In addition to measurements in the building, the algorithm can use electricity pricing, weather forecasts and consumption patterns to control energy storage and loads. All collected data is fed to a self-optimizing closed process loop, which, using adaptive proprietary algorithms, seeks an optimal control strategy.
How well is the energy storage able to handle power peaks? How large margins does the control system have to handle load variations? How is the wear of the energy storage minimized?	Peak shaving and minimizing battery wear have been given a medium priority. The capacity of the energy storage is 14.4 kWh, and by not allowing the state-of-charge to drop below for example 40%, a margin always exists to handle peaks and load variations of 5.76 kWh. It is not known which strategy is used to minimize wear on energy storage.
If load shedding is active, how does the control system choose to control the loads? At what times? Is weather data used to create an adaptive system? Can users control the load shedding themselves?	Weather data will be used to, involving machine learning, create an adaptive system for optimal load control. The algorithm itself allows for the user to enter temporary changes, for example if it is known that the building will be empty for some time. This feature is not implemented now, since it was not considered necessary for the optimization of the algorithm's function, which is prioritized right now.

When is the energy storage charged? Can it be adjusted for charging at times of low load or low electricity prices?	In addition to measurements in the building, the algorithm can use electricity pricing to control energy storage and manage loads.
During a sunny day of high PV production, how well does the system succeed in increasing self-consumption of solar energy?	In the algorithm, high priority is given to maximizing self-consumption of the produced solar energy. Based on the available measurement data, it is not possible to indicate how much the self-consumption increases due to the control system, since smart battery control was not implemented.

Certh is currently working on optimizing their algorithms for optimal load management. Certh is assessed to have completed its installation on the current site, but optimization remains. It can be noted that the control system should be able to handle both power peaks and to regulate self-consumption after completion of optimization, but any quantification of these goals cannot be done.

3.3.3 Security

The evaluation of the security aspects of the system solution was planned to be performed in connection to the completion of the technical evaluation. Now, the technical evaluation could not be finalised since the smart control still had not been activated. Therefore, some evaluation is performed of the security aspects, such as they are today. Complements may be needed in connection to the completion of the technical parts. According to Certh, the Equilly User application shows a graphic presentation of the internal conditions today. There is also real time monitoring of both internal and external conditions, such as energy patterns. Data may also be saved. The plan is that the user in the future will be able to give feedback on the system performance. The Equilly system is presented as a plug-and-play type, which gives opportunity upgrade the system without changing any specifications for the tools. The software can also be remotely upgraded under operation, which is a huge advantage. During upgrades, a short interruption of the Equilly User application is required, though that should not affect the system functionality.

3.3.4 Sustainability

Equilly is a software solution and thus less problematic when it comes to the sustainability aspects. Currently, Certh has no special requirements on any hardware. In the long term, ConvCAO will launch a hardware to meet the need to integration with a larger variety of production, real estate automation system, charging systems, and energy storage. This product will be based on the standards for sustainable electronic equipment and the company will follow the EU guidelines for re-utilisation, dismounting, and recycling.

As a software, Equilly can utilize real-time measurements and weather and price forecasts to control the microgrid for optimal load control, and thereby seems to have a has a high potential for creating energy efficiency, reduce the grid usage, and increase the usage of DC systems, which in all affects the product's life cycle perspective positively. These variables are the same for all the pilot systems.

3.3.5 Open Data

Equilly delivers five different interfaces: JSON, XML, Excel, and Math (which is CnovCAOs own platform) as well as an online data transfer. The company can also offer customised interface according to the customer's preferences.

Today, the system is used as an open API in most of the pilots, and thus has been integrated with other APIs and the company actively seeks to keep on integrating with all open APIs on the market. Keeping in mind that the system is a hardware independent software, this is not strange, but more of a sanitary factor for the system.

The system is based on an algorithm called PCAO, created by ConvCAO in a previous EU project and which is optimised for plug-and-play. This entails that the system does not need any predetermined calibration or resource-intensive installation. The system optimises itself towards the products and real estate automation systems it is connected to. Due to these reasons the system is well adapted for remote installation over the Internet. It stands clear that the system is not fully optimised since the pilot installation was not exactly plug-and-play, but the ambition is good.

The system is designed as an open application when it comes to data access. All data used for the system's decision processes are owned in common by the customer and ConvCAO and is available for the customer to distribute after agreement between the owners. The system app is open for integration with other solutions from third parties.

3.4 INNOENERGY

3.4.1 User friendliness

During the installation of InnoEnergy's solution, which went through Ihus, Ihus chose a larger electrical installation firm where one single person, due to his creativity, curiosity and good skills in data communication, proved to be of great importance for the project's implementation. This was to facilitate the installation, if possible, since Ihus already in the initial discussions realised that InnoEnergy is significantly earlier in its development than Ferroamp, for example. The basic installation went well. In the step before the installation, it took a long while to get an agreement, since InnoEnergy had troubles to secure internally the commitment to fulfil the required criteria for this type of commission.

InnoEnergy's organisation, among other things that they lack an installation resource of their own, led to the involvement of many actors, which in turn led to some unnecessary delays and difficulties in establishing efficient communication and information.

3.4.2 Technology

InnoEnergy's system solution consists of a management and control cloud service and a hardware interface for connecting battery storage and local power solutions. The plan is to use machine learning algorithms to better predict loads, PV production, electricity prices etc. A large amount of measurement data is collected and utilized, such as from the DC and AC side of the battery storage, calculated values of the plant's energy requirements based on energy measurement of import/export from the grid and PV system, as well as current, voltage, frequency and power both single phase and three-phase. Since remote software upgrades are possible without changes to the physical installation, it is possible to implement this upgraded software also on this site. The system solution provides great flexibility to handle different users' systems and the flexibility to connect devices. Below is a summary according to the bullet list in the method section on page 7 in Appendix 1.

Analyzed parameters - InnoEnergy	
When does the control system choose to start discharging the energy storage? Are these decisions based on previously obtained measurement data? Is the system adaptive and can it handle changes in load and production? Does the system handle differences in load and production between different days (weekdays/weekends)? Is weather data used to forecast PV production and thus control the energy storage?	A smart-battery management system has been adjusted based on analysis of historical consumption and production patterns and is adaptive. The system adjusts its control after the season and applies energy arbitrage. Today, prediction of load or PV production is not implemented, but under development.
How well is the energy storage able to handle power peaks? How large margins does the control system have to handle load variations? How is the wear of the energy storage minimized?	Medium priority has been given to minimizing power peaks, by adjustment of charge and discharge currents so that the battery should not have a too low state-of-charge to handle a power peak. Minimizing wear on the battery storage has been given high priority in the algorithm. The state-of-charge of the battery is kept within predefined safety margins, and when these margins are exceeded, top priority is given to restoring the state-of-charge level. The capacity of the energy storage is 20 kWh, and by not allowing the state-of-charge to

	drop below 40% (controllable), there is always a margin to handle peaks and load variations of 8 kWh.
If load shedding is active, how does the control system choose to control the loads? At what times? Is weather data used to create an adaptive system? Can users control the load shedding themselves?	Load management is facilitated by the fact that energy arbitrage and functions to control self-consumption are available. At present, optimization of algorithms for optimal load management involving machine learning is performed. The user can control his system by making three basic choices - between standby, normal function and at which power level charging/ discharging of the battery should take place.
When is the energy storage charged? Can it be adjusted for charging at times of low load or low electricity prices?	Medium priority has been given to minimize costs by using electricity pricing data.
During a sunny day of high PV production, how well does the system succeed in increasing self-consumption of solar energy?	Maximized self-consumption of produced PV power has been given top priority in the system. Based on the available measurement data, it is not possible to indicate how much the self-consumption increases due to the control system, since the collection of measurement data before and after installation of the algorithm, corrected for variation in load and consumption patterns was not collected within the scope of this project. See also the introduction in Chapter 3.

InnoEnergy is assessed to have completed its installation and commissioning.

3.4.3 Security

The system solution is based on using external hardware from a third part in the installation, and thus it is not meaningful to evaluate standards and warranties.

The system solution is based on a PC based industrial automation platform, an open interface standardised PLC, characterised by openness, interoperability, and modularity. Thus, it can be combined with products from any producer. Different standard modules can be integrated seamlessly with the system to support different kinds of sensors, that can be used to increase the accuracy in the measurements, and later on in the control. No proprietary interfaces are used in the system. The system allows remote updates of the software, and the system is functional as long as the power grid is functional.

The system can partly be controlled through a web portal, represented by a SCADA dashboard, where system configurations and real time data of relevant parameters for the different components (load, solar electricity system, and battery system) are presented. The battery system can be remotely controlled in three different modes:

- Stand-by
- Charge/discharge at a specified effect level
- Use the automatic algorithm

History data are presented graphically, and temporary interruptions of the internet connection are managed by data being saved locally and later sent to the cloud as soon as the connection is re-established. The web portal can also be adapted to the user's specific needs, which means that the evaluated portal isn't necessarily the final portal. In the basic configuration the portal contains a system overview were very detailed data over loads, converters, export/import from the net, PV production, and battery parameters are presented and can be processed.

3.4.4 Sustainability

The control system contains an integrated mini PC, electric sensors, and wiring. The main component of the system is the integrated computer and InnoEnergy seems to have a very good structure for re-utilisation, and recycling of the product, which is calculated to be in use for 20-30 years. The following parts of the product components are reusable (30-40%): wires, electronic parts of the computer, inlet/outlet modules can be re-utilised for integration with newer PC modules. The following parts of the product components are recyclable (90-95%): Metal and plastic casing, electronic parts of the computer.

The life cycle analysis is not carried out, but the fact that InnoEnergy applies a responsible design and follows the code of conduct for PC manufacturers, (CoC), regarding social responsibility, created by ZVEI, (the German electricity and electronics manufacturer association) grants a sustainable course of action.

3.4.5 Open Data

The communication interfaces offered are Mbus and CANbus. Communication and APIs to and from electricity meters are standardised, but for battery storage there is still no standard for communication and interface. This entails more manual labour for integration. When the battery storage market is standardised, the plug-and-play level for these systems will increase.

The system is based on a standardised industrial platform, containing an open interface with high interoperability. No proprietary systems are used. Since InnoEnergy's business model is to integrate with as many different system solutions as possible, it's in the company's interest to keep completely open interfaces.

4 Evaluation of Business criteria and Organisation

4.1 Ferroamp

4.1.1 Current status

Ferroamp is the closest to commercial operation, and as expected, the installation itself presented no problems. Though Ferroamp had difficulties delivering the products on time, which led to time schedule delays. After the installation, there is a lack of training, introduction, and documentation for the customer. Ferroamp has begun a market introduction and thus has a strained organisation and a structure under development. The decision to place Ferroamp's installation with Ihus, must be regarded as correct, even though it put some extra strain on Ihus. It stands clear that Ihus engagement has been vital for the smooth running of the project so far. Ferroamp completed the installation in the end of August 2017.

Ferroamp finished the physical installations of their components in the beginning of June 2017. Then RISE got access to the cloud-based portal 27-07-2017. An initial analysis of the measured values showed an existing error, that led to the installed battery storage did not charge. This was taken care of in the beginning of August, after which an analysis of the measured values commenced. After contact with Ferroamp, new problems with the parameters in the control system were identified, and the desired functionality was not achieved. Ferroamp then took on to update the system parameters to optimise the system before the factual evaluation of the system was performed. During the project, development of a new platform, Yocto, has commenced, to directly connect the components to a secure server to facilitate remote updates, troubleshooting, and log checks. Through the Yocto platform the systems can be controlled from connected services and through a portal. All parts of these outer systems are not developed, but new functionality and implementations are added, thanks to the new platform.

4.1.2 Organisation

Today Ferroamp has a staff of 19 people, and a business plan aiming at break-even at a turnover of 35 million SEK. Budget for 2017 shows a turnover at 10 million SEK. In 2017 the company has delivered for 6.5 million SEK. The negative return, on the way towards black numbers, is balanced with a bond issue to existing owners and a new issue of shares within the next 12 months, directed at selected, larger investors.

4.1.3 Business criteria

Ferroamp's business model is based on sales to distributors and integrators by supplying them with documentation and relevant sales support. Then they sell on the product to end customers, often in a system or with a service. This business model must be seen as fully scalable. At an international expansion the company needs to establish channels in each country. These channels will probably be in the form of partnerships with appropriate competences and organisations.

Today, the company is financed for the next 6 months. The strategy is, with the return for 2017, the volume increase from 2 to 10 million SEK, and based on a verified delivery ability, gear up aiming at a powerful market venture within and outside Sweden.

With Ferroamp’s solutions you can create a fully integrated platform with local production, battery storage, charging infrastructure, and building automation where, with traditional systems, you are reduced to use isolated, stand-alone solutions. Within the area the company holds several patents, both for hardware and software, that they consider to be completely unique and highly valued patent.

The advantages with the company’s system solutions entails e.g.:

- Central investments, (sun, wind, battery, charging infrastructure), which means lower investments and losses.
- An encompassing coordination of the building’s consumption, production, and storage of electricity gives the opportunity to efficiency optimisation.
- Energy and efficiency data, stored in a central cloud platform, creating possibilities for service suppliers wanting to complement their services with system solutions, based on solar electricity, electric car charging, and energy storage, as well as solar cell installation engineers, wanting to develop service offers with energy streamlining, helping the customers with effect control.

With its concept, Ferroamp is positioned centrally in the value chain of energy-related services. The offer to the net companies is to manage the challenge around growing problems with varying effect in the power grid due to increased local production and usage.

The offer to the service companies and contractors is to develop added value services based on the energy and effect data that Ferroamp supplies, which can create efficiency minimisation and surveillance services for real estate companies.

Ferroamp has chosen to create a completely integrated system. Competing, and significantly larger, established actors sell part solutions, but no one have followed the same line as Ferroamp. At the same time, the prime focus for the other tested system solutions within IEM is software development, but they are forced to develop hardware for connecting to existing system. In the light of this, three scenarios may be dominating in the future, separately or combined:

- It is lucrative in the short term for established companies to counteract integration solutions for the benefit of their own systems.
- A standardisation of included components, such as local energy production, energy storage, building automation systems, cloud services, etc. will grow and facilitate for system integrators to build complete systems, like Ferroamp’s solution.
- A corresponding standard is emerging on the hardware side in the form of boxes with generic connections to loads and control systems.

The development of standards for bridging systems has not yet started. Though Ferroamp’s competitors come from the software side and notes this development, which partly might undermine Ferroamp’s business in the long term.

Ferroamp’s business approach might be seen as well adapted to current legislation and market development. The potential legislative changes within the area probably will not affect Ferroamp's business negatively.

The trend towards charging for effect rather than energy favours the company and from an international perspective it is conceivable that future national legislation follows the international development and give increased support to this development. A potential obstacle is that certain countries may introduce concession for network companies with sole right to distribute electricity. It makes it illegal in these countries to connect different consumers without passing the consumers electricity meters. It is more probable that most countries chose to legislate for making it possible for customers to connect to each other through DC connections with the purpose of supporting introduction of local energy production and energy storage. This scenario would support Ferroamp’s system solution.

4.2 Amzur Technologies

4.2.1 Current status

The original analysis that Amzur is the farthest from the market is not completely accurate, but the engagement of Magnus Nilsson at Glava in the project has been totally decisive for the work in establishing the pilot. Both the software and the hardware installations were finished within the framework of the project and test and verification could be performed according to the time schedule.

4.2.2 Organisation

Amzur is a privately-owned, joint-stock company, founded in 2004 with more than 200 employees. The tested solution within IEM is called OpenDEM and in this team currently occupy 5 full-time employees and 4 contracted consultants. The development in the area is financed through other company activities.

4.2.3 Business criteria

Amzur’s market strategy is based on supplying communication and control within an open source model for distributed renewable energy, OpenDEM (Open Distributed Energy Management).

The company uses Red Hat, which is an internationally established source code model. Amzur uses the technology in Kitware, which is integrated into a wide selection of devices and software.

Amzur's current activities are based on delivering adapted software, services, and support. The company estimates that their proceeds from services and support will amount to 10 million dollars during the first 10 years of commercialisation.

Amzur do not intend to sell directly to end users, but through a network of product sellers and distributors. In its current operation the company is successful when it comes to creating long-term customer relations for their ICT solutions and believe that those channels can be expanded with a wide spectrum of partners among distributors, wholesalers, energy storage companies, inverter producers, solar cell suppliers, and other energy services.

Amzur's strategy is to become established as a leading software supplier within the area. For this purpose, Amzur has several pilot projects, contributing to the development of OpenDEM. In the “Orange Button” initiative an UML and API are developed for open source. With Argonne Labs, a software for low-cost submetering is developed. With Oak Ridge National Labs, a control device is developed, based on open source for micro nets and in collaboration with Smart Energy Power Alliance, (SEPA), a web seminar is developed to integrate the installations behind the electricity meter which are owned by the installation owners.

The company has no patents, their source code will be available under an open source licence. The platform will support the integration of proprietary algorithms from third part suppliers through open standardises interfaces.

The company sees its strategy around open source and supplier neutrality as their strongest asset to influence other market actors and the market in total, to drive development. The company's system for open distributed renewable energy is seen as a way to significantly reduces the introductory cost for new technology and new market actors (converting, battery and load control, cloud services, etc.). The OpenDEM platform may reduce the costs for integration, and when the standards for these systems are set, the market will develop faster. It is in the supply of the platform for integration of these functions and services, based on existing and new standards, where Amzur sees its position in the value chain. When it comes to competition, Amzur sees a wide range of suppliers and solutions, offering proprietary hardware and software for energy storage, smart thermostats, load control devices, real estate automation systems, advanced distribution systems, etc.

4.3 Certh

4.3.1 Current status

The analysis that Certh, from a market perspective, was positioned somewhere between Amzur and Ferroamp was wrong. Certh is assessed to be later in its development than Amzur, and the main reason that the installation was finished is due to Per Ekstorm's knowledge and engagement. That said, Certh is assessed as one of the system solutions farthest from market introduction. The software installation was finalised in April 2018 and the training of the self-learning algorithm began during the last days in April.

4.3.2 Organisation

The Agile system is renamed to Equilly, but the ownership remains in ConvCAO, which is a jointly owned public and private institution within Certh.

The private owners consist of the 10 people at the University, who also make up the staff resources of the group. The team consists of resources with different technology backgrounds, with focus on development of intelligent, fast implementable, and self-learning control systems, and their application within large-scale systems like traffic control systems, real estate automation systems, and smart power grids. At present the group consists of 10 people, including technicians, product developers, and software developers.

The group claims to be around 12 months from market introduction without direct external financing and base their finances on participation in three demonstration projects on EU basis with a total of 2 MEuro.

4.3.3 Business criteria

ConvCAO has not yet finalised its business and financing plan for the market introduction of Equilly. Thus, the company has no contact with investors, but plan to finance the introduction through organic growth and external investors.

The company has no patents or IP but claim that their IP is protected, since the customers are not allowed to directly access their own algorithm and the software, controlled by the algorithm.

The Equilly software for plug-and-play installation and self-learning system for calibration has the potential to drive the market forwards and increase the profitability in total for local production, energy storage, charging infrastructures, and real estate automation.

The purpose of ConvCAO is to facilitate installation, integration, and calibration. That said, ConvCAO’s position in the value chain is to offer technology suppliers and integrators an additional module, software, and a cloud service to minimise manual programming and calibration.

Within the frame of the pilots carried out, ConvCAO has started to think about developing a hardware device to facilitate the integration of their software with other systems. The current systems on the market are difficult to integrate with other solutions and thus have limitations when it comes to achieved energy efficiency. That said, a fully functional, open plug-and-play system, minimising installation, integration, and calibration, has large opportunities to compete with these existing systems.

Finally, ConvCAO means that the largest threat in changed legislation may be a stricter legislation in data security issues. Though, these potential obstacles may be met with upgrades of security solutions and security routines.

4.4 INNOENERGY

4.4.1 CURRENT STATUS

The finalising of agreements delayed the time schedule somewhat, and a lesson can be derived from this, that the process for developing an agreement for the pilots could have been conducted with extended consultation and given more time for discussion. Although InnoEnergy was the last to enter the pilot, the installation went fast and without complications.

4.4.2 ORGANISATION

InnoEnergy's team in LSO (Local System Operator) consists of Vladyslav Milshyn, business development engineer and pilot project manager; Fredrik Billing, LSO project manager and an experienced business coach for innovative technology companies; Doctor Arshad Saleem, technology expert in Smart Grid and energy storage, and Raghunath Vasiredy, integrated systems engineer.

The system development is performed according to InnoEnergy's development process, based on the SCRUM principles (an iterative and incremental program development framework for managing product development).

The development involves a network of innovation companies, innovation projects, experts from InnoEnergy, as well as consultants from Sweco, with experience from this type of projects and established risk management processes.

The group claims to be around 3-6 months from market introduction without direct external financing and base their finances on participation in three demonstration projects on EU basis with a total of 2 MEuro.

4.4.3 BUSINESS CRITERIA

InnoEnergy supplies a cloud service, as well as a hardware interface for connecting battery storage/local energy solutions. The hardware is purchased and equipped with InnoEnergy's algorithm and cloud service. InnoEnergy's business model is based on installation of systems through installation engineers and integrators- For InnoEnergy to succeed, the company needs to find partners, who can support them with installation and procurement. The offer is based on InnoEnergy being able to improve the efficiency in the customer's installation of local production and energy storage. The revenue flow is built on a fixed income for data gathering and supplying the user interface, as well as a basic level of self-sufficiency, followed by extended services for a higher level of self-sufficiency with frequency regulation, effect regulation, etc.

The pilots performed within the current EU projects in common with the Swedish Energy Agency aim to verify technology and identify key partners. At the market introduction within 3-6 months, LSO will be placed in a private company.

InnoEnergy has no current patents or IP but are highly interested in making the system algorithm their IP. In Germany and Great Britain, where the legislation has become more open, there are similar operations. For example, SonnenBatterie, which started as a battery supplier and has developed a similar role as InnoEnergy. InnoEnergy's present role is based on current legislation and all tests emanate from this.

4.5 The ability to provide flexibility in the system

Even if these system solutions have the potential to increase flexibility in the energy system, a full-scale solution is a relatively complex system to set up. For example, the system requires interactive inverters, and a management system that can create a bidirectional, interactive system.

All in all, it can be concluded that when the solar energy penetration grows, the power distribution system will experience larger current flow variations and voltage fluctuations. To increase the capacity (and flexibility) of the energy grid to handle more distributed energy, a moderation is required to reduce the variations created by for example solar and wind energy. Each of the tested systems are designed to reduce the effects of variations in solar generation through usage of energy storage and intelligent load control. The systems charge the battery system when the solar energy facilities generate surplus energy and make it possible for the operator to shift or push the load to occasions when user-defined thresholds are reached.

At present, these systems and their energy storage are contributing to a good solution for increasing the flexibility in the energy system. The batteries' ability to render instantaneous current within a very short time-frame of microseconds, can balance the demand and the energy supply in a reliable manner. An example if this is Ihus' pilot installation in Vaksala Eke, where an energy management system (EMS) has been tested. The EMS supervises the current flows (grid import/export and local production) and activates the battery storage system to optimise the cost for the energy imported from the grid. This is performed by managing the peak power outtakes to achieve a more level energy consumption profile during the day. The battery storage system improves the use of the energy produced locally by solar and wind resources, which in turn increases the amount of renewable energy in the energy grid. Within the projects pilot installations, the consumption of locally produced solar energy has increased from 90% to 95%, and the export of energy to the grid has been reduced with 60-65%. The maximum consumption during winter, (≈45 kW), can be reduced with around 10%, contributing to the flexibility of the energy system during the critical winter periods. From a wider perspective, these numbers could be increased further if the EMS get access for controlling other loads (heat pumps, ventilation fans, etc.) in the building. An increased number of buildings equipped with these systems entail a raised ability to contribute flexibility to the energy system.

5 COMPLEMENTING ANALYSES

5.1 MARKETING PREREQUISITES FOR IEM SYSTEMS

During autumn 2016, the consultancy firm WSP was engaged to perform a market analysis for IEM system solutions. As a basis for the analyses, a survey was made of the market development for battery storage in real estate applications. The analyses were concluded and presented in the middle of March 2017. The WSP reports are summarised in short below. The reports are appended as well.

5.2 THE MARKET DEVELOPMENT FOR ELECTRIC ENERGY STORAGE IN REAL ESTATE APPLICATIONS (APPENDIX 2).

As a basis for analysis of the future market for IEM solutions (see below), WSP made and account of solutions for electric energy storage at estate level. The account focuses on available technology, ongoing development, as well as demonstration and pilot project.

The study begins with a description of the needs definition for on-site electrical energy storage, which short can be summarised as follows. The energy storage aims for:

- Cost optimisation through price-per-hour agreements or similar.
- Reduced effect outtakes at peak loads – lower energy and/or grid cost.
- Increased usage of local energy production, e.g. wind and solar energy.
- Use of on-site reserve power and the possibility to manage specific requirements on electric quality.
- Support for local micro grids in buildings or areas.

The study then makes a wide survey of different electrical storage technologies and their respective advantages and disadvantages. The study focuses on the technologies assessed to be closest at hand for on-site application, above all different electrochemical storage technologies (Lithium-Ion batteries, lead–acid batteries, flow batteries, sodium-sulphur batteries, metal-air batteries), as well as studies of storage in the form of hydrogen ("Power to Gas"), and sensible heat storage. Finally, around 10 projects are described, where the storage technologies are applied.

5.3 Survey of market prerequisites for IEM system solutions (Appendix 3)

The market prerequisites for IEM system solutions are described through a scenario analysis of the future market, with a 5-year and 10-year perspective, respectively. The study focuses on the Swedish market, with an outlook on the international market. The study includes IEM solutions where the energy systems in buildings are adapted for using and storing self-produced solar energy locally to a larger extent, and thus reducing the need of electricity from the grid, by adapting the energy consumption and control the charging of battery storage.

The study starts with identifying the key factors that may affect the market development of IEM systems. Overall it concerns the political focus of the Government for the development of the electricity energy system, e.g. the degree of renewable electricity production, and the incentives and instruments which then will come into question. How the electricity system is developed will also directly affect the degree of motivation for investments in IEM system, e.g. through the electricity cost level and cost volatility. The development of the amount of solar cell installations and battery storage are of course vital for the development of IEM systems.

Thereafter, the study presents a qualitative analysis, partly based on a scenario analysis from the Swedish Energy Agency, called "Four Futures - the energy system beyond 2020", published in April 2016)

Qualitative analysis

The analysis indicates that the *Espressivo* scenario has the best prerequisites for IEM solutions.
In this scenario, the State focuses on individual solutions and a decentralised energy system, and the amount of renewable energy is relatively high (75%). The flexibility when it comes to the demand is important, and the responsibility for electricity supply is decentralised. The *Vivace* scenario entails good prerequisites for IEM solutions as well. The amount of renewable energy is close to 100%, but the local perspective is not as strong. The *Legato* scenario brings slightly lower prerequisites for IEM solutions. The amount of renewable energy is close to 100%, here as well, but a strong political governance renders low electricity costs, which works in a negative direction. The *Forte* scenario is the only one assessed to be directly negative for the development of IEM systems. The scenario entails a strongly centralised electricity energy system with a relatively low degree of renewable energy (50%).

5.4 Obstacles in development of sustainable local energy systems (Appendix 4)

In connection to the analyses above, an interest emerged, to study the obstacles when it comes to distributed energy system solutions, built on local production. If such obstacles can be removed, the market for IEM system could be developed faster. The consultancy company Profu was engaged and presented their analysis in June 2017.

The work is based on ongoing and finished investigations, studies, and research projects, e.g. Profu's report “Expansion of solar energy in Sweden - Possibilities, challenges, and system aspects”, and the Swedish Energy Agency’s reports, e.g. “What controls and hinder solar energy in Sweden?”.
The analysis includes a description of strengths and weaknesses in sustainable local energy systems (solar energy in particular), from a system and societal perspective, an account of the most important obstacles in the development of local energy systems, and an overview description of examples of similar discussions in Denmark and Germany.

For strengths and weaknesses, the issue is raised that there may be reasons for society to put emphasis on decentralised/local electricity production. The direct system benefits are assessed as probably small in Sweden/the Nordic countries. The non-technology benefits (e.g. That a venture is a way to increase the individual engagement in the conversion of the energy system and for environmental issues) are difficult to quantify as well.

The obstacle analysis points out difficult regulation frameworks, and support system, as well as bad coordination between different financial instruments (e.g. tax reduction for “exported” solar electricity and battery support). The investment support for solar electricity is also assessed to slow down the marked due to long processing times. The current tax reduction is uncertain, since it has no fixed duration, and thus is difficult to weigh into investment cost estimates.

For obstacles due to the grid concession, it is pointed out that there are exemptions from the relief from connection obligation, where nets are exempted from the concession obligation, (SFS no: 2007:215. Ordinance concerning exemption from the requirement for a grid concession under the Swedish Electricity Act). The exemption from the requirement for a grid concession requires an internal net, without extensive distribution, that must be easily limited (e.g. internal nets on or in buildings, or areas with hospitals or schools). Electrical networks or power lines in or on a building may be used to transfer electricity to other without a grid concession (e.g. rental apartment buildings). Internal nets, connecting several electricity production installations that together forms a functional unit, do not require grid concession (Section 22a). This exemption is particularly interesting since it should entail that a network, exempted from the concession obligation, could exist if there are solar cells on several buildings in an area.

5.5 NEEDS ANALYSIS, RESULTS FROM INQUIRY, APRIL 2018, (APPENDIX 5).

As a complement to the previous market analysis (Spring 2017), Sustainable Innovation made an inquiry, aimed at potential customers of IEM systems. The inquiry was performed in April 2018 and sent to around 150 people and rendered a total of 40 answers, which were compiled and presented in May 2018.

The enquiry describes IEM system as "solutions for control if charging and discharging energy storages or control the effect from, e.g. a heat pump from parameters as electricity production, access to stored energy, energy costs, and "peak loads".

The major part of the 40 answers, (45%), represents municipal property owners (including property companies), followed by private property owners, (22%). Among the answers there are also representatives from some energy companies, (15%).

As for the needs the IEM systems are to solve, most state that it concerns levelling the effect outtake and reducing the need to buy energy. Among the important prerequisites for the interest in IEM systems, issues such as better profitability and developed technology functions are raised.

For key factors to accelerate the market for IEM systems, "enhanced benefit compared to cost", "more local energy production (solar cells, etc.), and "access to vendor independent solutions", rate the highest, and most, (70%), believe that the key factors will be realised within five years.

Most of the respondents, (36 of 39), have solar electricity installed, and on average they see an increase of the installed effect with a factor of 3.7 in five years. Most of the respondents, (35 of 39),believe that they will have local energy storage, e.g. for storage of solar electricity and/or cutting peak loads, but only for individual buildings. Five of the respondents believe that they will have such installations in a major amount of their buildings.

The time frame for assessing when half of their own buildings will have IEM systems is within 10 years for around 40% of the respondents, while around 60% believe that it will occur later on. Around 80% believe that a penetration of 10% will occur within 10 years, and around 40% within five years.

When it comes to business model, most, 70%), want to invest in solutions for local electricity production and IEM systems, as well as be responsible for operation and management.

6 Discussion and conclusions

6.1 Software, hardware, or system solution

The fact that three out of four systems solutions are pure software solutions and that everyone has focus on the software side, shows that these innovation companies may also come from the IT sector and not as you can imagine, from the energy sector. Pilots are always interesting for both parties, and in the pilots performed by IEM it stands clear that the system suppliers embrace knowledge. In this case, both InnoEnergy and Certh stated from the beginning of the pilots that they plan to launch hardware for bridging their software with as many variations of installed systems as possible. There are only two ways to make the integration efficient. Either you own the full chain, like Ferroamp, or you have to supply some form of interface between software and real estate automation system, solar cells, battery storage, charging infrastructure, etc.

6.2 The integrator role

During the installation, the value of well-educated and engaged integrators stands clear, since the current electrical engineers do not have the education level in IT communication required for taking these systems into operation. This is an obstacle for these software companies, which must be taken care of before a market introduction. In order to facilitate this work, the growing industry should also agree on the use of open standards.

6.3 Market introduction

Except Ferroamp, which is in the early phase of market introduction, these system solutions have at least 6-12 months left to market introduction. At the present, all of these, (and in part Ferroamp as well), have grant-based financing outside the market. Amzur is an exception, since the system solution is a part of a larger concern, partly financing the introduction. All in all, the analysis entails that after Ferroamp, Amzur and InnoEnergy will reach market introduction within 12 months.

6.4 Matching of system solutions and stakeholders

The fact that the tested system solutions are more and less far from the market, was initially considered in the evaluation of where each system solution would be placed. The analysis that Amzur was farthest from a market introduction and thus needed a non-public environment and that Ferroamp already reached the market and didn’t need the same kind of support, where both only correct in part. It has become apparent that all system owners have had various kinds of difficulties with the installation when taking systems into operation.

6.5 Technology, resources and dialogue affects the time schedule

It became apparent that the technology aspects of the pilot installations were not the only issue at this point. During several of the stages of commissioning the installations, the dialogue has been insufficient. Primarily on account of the companies' own lack of resources, but to a certain degree due to the geographical distances and linguistic barriers. The combination of these parameters has created delays in the time schedule. These factors could in part have been predicted, since the evaluation concerns innovation companies. In retrospect it would have been wise to calculate a twice as long installation and calibration period for the pilots.

6.6 Factors to weigh in during pilot installations

When building innovation project like these, linguistic barriers and geographical distances should be considered. A supplier from Greece or the US do not have the same opportunity to get on site to take care of the installation, while the linguistic barrier increases the risk for misunderstandings. No matter if it is a pure innovation company, or a company recently introduced on the market, these companies lack resources in one way or another, delaying deliveries, installations and calibration. Thus, it is wise to include this from the beginning. Since the innovation companies' resources are limited, pilots like these require engaged and knowledgeable customers, installation engineers, and integrators. In these pilots the customers have been engaged and knowledgeable, but the installation engineers, and integrators do not always have a similar level of engagement and knowledge, leading to additional work and delays.

6.7 The sunlight exposure's effect on the time schedules

Given the delays in the installation phase, the project was prolonged to achieve the technology evaluation in April, with sufficient levels of sunlight exposure. In the original project plan (including delays), the sunlight exposure was reduced since the evulation fell on autumn/winter and the days became darker. At the same time the energy consumption increased in the buildings after the Summer vacations. This entailed a possible problem in the technology evaluation, which risked being severely limited if the produced energy from solar electricity installation never exceeded the loads of the building. To evaluate the solution's possibilities to increase the energy consumption of self-produced solar electricity the optimisation of the systems should be performed when the production form the solar energy installation is high or at least at mid-level. The exception is possibly the solar installation at Slagstaskolan, that is relatively large in comparison to the existing loads, which entails that the possibility to perform the technology evaluation could have been performed during periods with lower sunlight exposure than the other pilots.

6.8 Technology

The main focus of the evaluation is to give a qualitative description of how the system solutions work, with lesser focus on quantitative objectives. The presentation of quantitative data require that the systems are fully optimised and have been operational for at least one year. At present, this is not the case for all participants. It is not possible to quantify how well the energy storage manages peak loads in any of the installations, only to state that the systems manage peak loads through using the battery storages. The data entails that self-consumption exist. Though quantifying the increased self-consumption in relation to how the self-consumption would have been without SEA is not possible.

Ferroamp

Ferroamp's technology solution offers a fully scalable system where everything from energy storage, and converters, to control systems are offered in a comprehensive solution. The system is based on a smaller local direct current net (DC net) with an operations voltage of 760 V DC, (±380 V DC), being integrated in the building. Direct current loads, solar electricity production, and any energy storage are collected behind one converter, even if the system is expanded and changed at a later date. The control is the same for all sizes of installations, which means that users can benefit from for example battery technology developments, new business models, or new legislation. Ferroamp's solution is based on a self-produced hardware system where the core is the so called EnergyHub system. The EnergyHub system consists of a scalable, bi-directional converter, that can convert energy to and from the direct current grid and the alternating current grid. The control system in the EnergyHub communicates with high solution electricity meters and sensors, located at loads, the solar cell installation, as well as at the incoming line from the power grid. The measurements are performed on the second level, where all measurements are stored on a physical hard drive. Calculations and similar are performed directly, and the calculated values are transferred to the cloud service. Through developed algorithm and pre-set settings , the EnergyHub controls the energy flows between solar panels, energy storage systems, and the power grid. From the developed cloud service, users can follow and monitor the system functionality and their own consumption statistics. In addition, several different analysis services are offered, where the users can analyse phase imbalances, needs of expanded energy storage, and simulation tools to save energy.

In addition, a system for phase compensation named Adaptive Current Equalization (ACE), is integrated in the EnergyHub. The system is meant to prevent fuse overload due to large asymmetric current fluctuations and levels the magnitude between phase currents. In this way, the fuse rating in the buildings can be reduced, and thus save money on reduced power grid fees.

In addition, Ferroamp has developed an energy storage system called Smart Energy Storage, specifically adapted for working with the EnergyHub system. The system consists of lithium-ion batteries, controlled by an integrated battery monitoring system to maintain temperature, control charging cycles, and optimising the battery cells. The energy storage system is available in sizes of 7.2 kWh and several individual systems can be connected to increase the capacity. A bidirectional DC/DC converter, Energy Storage Optimizer, is developed for integration of energy storage systems with varied current levels.

In addition, a self-developed solar string optimiser, (Solar String Optimizer), is offered for any solar panel installations to control and maximise the efficiency of the solar panels. The control device is directly connected to the EnergyHub and can be remotely turned on and off. The control device requires constant communication with the EnergyHub and if any errors or accidents occur, the control unit will be shut down automatically for increased security.

Amzur Technology

Amzur’s system solution only includes a control device, installed in a regular personal computer with the open and free operative system Linux. In addition, the system solution requires a converter for a specific standard, Sun Spec Rule 21, developed by the industry organisation SunSpec Alliance, and specifically developed for converters used in smart electricity grids. Amzur also contributed with developing the design for communication and control systems for energy measurements, load control, and battery control for the Glava pilot installation in question. These systems are adapted for the pilot site in question and is not a part of Amzur's proper system solution. Therefore, the functionality and standards for these system components will not be evaluated in detail, but to give a picture of this instance of the system implementation several functions are presented below: For example, the Glava system cannot export effect, that is why maximising of the self-consumption and storage naturally get a high priority in the algorithm. Minimising other issues, related to electricity quality, e.g. Quick voltage changes, or levelling of quick changes in load and production, will not be considered. Minimising peak loads (peak shaving) is highly prioritised in the algorithm and based on user-defined parameters. When it comes to cost minimising, SOW does not include BTM Economic Dispatch, but such a term could easily be implemented in the algorithm in question. Minimising battery wear is also highly prioritised, and the charge and discharge cycle for the battery is based on available prognoses for load and solar energy production. To minimise the effect on the user's comfort and to facilitate cost minimisation, for example is the user knows that the building will be unused at times, the user controls the parameters for load control, and the system allows temporary changes in the load control schedule.

The control system is the core of Amzur's system solution. It is based on CSEISMIC (Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Controls), a system developed by the US National Research laboratory Oak Ridge National Laboratory (ORNL). SCEISMIC is a control system, adapted for micro grids with a high amount of renewable energy, that monitors and controls various components in the micro grid.

Initially the plan was to use machine learning, or MILIP. Though it emerged that the Glava facility was not suitable for advanced optimisation, given its relatively simple build with only two loads and a fixed user profile.

To achieve a complete plug-and-play solution, smart hardware is required, for example an USB arrangement, that exposes its functions automatically. Amzur’s plug-and-play solution is aimed to meet industry standard DER protocols, primarily SunSpec, MESA, and SEP2 (IEEE2030.5). With the experiences from the project, it would be relatively simple and cheap to develop a plug-and-play hardware, but this is at the planning stage at the present.

Certh

Certh's system solution consists only of the so called Equilly algorithm (previously the Equilly algorithm), aimed at implementation in hardware, supplied by a third party. Through real time measures from the solar cell installation, energy storage system, and electricity consumption, the micro grid is controlled to optimise the control objectives. Except measurements in the building, the Equilly algorithm can used electricity prices, weather prognoses, and consumption patterns, to control energy storage and controllable loads. All collected data is fed into a self-optimising, closed process loop, that through adaptive self-developed algorithms seeks an optimal control strategy. The algorithm itself has support for the user to enter temporary changes, for example if the building will be empty during a period of time. In the current case, this function was not implemented since it was not considered to be necessary to optimise the algorithm function.

In the algorithm for the control system, maximising self-consumption of the produced solar energy is highly prioritised., as well as minimising effects on user comfort during load control. In the algorithm, cost minimisation through real time data for electricity pricing is usually highly prioritised, but cost minimisation was not applicable for this installation, since the electricity pricing gave no room for this. Minimising peak loads (peak shaving) and minimising battery wear are given medium priority. Other possible control objectives, for example minimising electricity quality issues, like fast voltage changes or fast changes of load and production, are not included.

In the figures below, energy consumption and energy, produced by the solar cell installation are shown. The battery control was not functional during these measurements. The Equilly installation has the largest solar cell installation, 85 kWp, and the graphs below shows a large potential for a major portion of the installation's energy consumption at these loads, might come from the solar cell installation.

The installation has, at the time of writing, been completed, and collection of measure data is possible. Though a complete evaluation of the technology aspects of the system is not possible, since smart battery control has not yet been activated. From the available current data, it is only possible to state that the solar cells produce a considerable amount of energy and that the measurement data collection works.

InnoEnergy

InnoEnergy's system solution partly consists of a cloud service for control and adjustment, and partly of a hardware interface to connect battery storage and local energy solutions, with assistance from a CAN bus for fast and secure communication between different nodes in the system, and an m bus for communication and remote reading of measurement data. A smart battery management system is under development, but not completed for evaluation on this site. The plan is to use machine learning algorithms for better prediction of loads, solar electricity production prices, etc. Today the prediction of loads or solar electricity production is not implemented, but the battery control system is adjusted, based on analyses of historic consumption and production patterns. Since remote upgrades of the software is possible without changes in the physical installations, it is possible to roll out that upgrade on this site as well. The hardware is purchased and equipped with InnoEnergy's algorithm and cloud service. Through this, the flexibility is large for managing many different systems as well as flexibility for connecting and disconnecting devices. From the system a large amount of measurement data is collected, for example from the DC and AC sides of the battery storage, calculated values of the installation's energy needs, based on energy measurements of import/export from and to the grid, as well as solar electricity production, power, voltage, frequency and effect for both single-face, and three-face.

Maximising self-consumption of produced solar electricity is given the highest priority in the system, insofar as when there is a surplus of self-produced solar electricity, the import of energy from the grid is locked to zero, and the rest of the functionality cannot be applied.

Minimising the battery wear is also highly prioritised, insofar as battery charging is operated within secure SOC (state-of-charge) limits, and if the battery storage ends up outside these limits, the priority of all other functions is lowered, until the battery SOC is reset within the secure limits.

The user comfort is not affected by the system's basic prerequisites, since ventilation, heating, and lighting are not controlled. Managing is only performed toward the power grid connection.

The minimising of peak loads is given medium priority, through adjustment of discharge flows during times of high loads, based on SOC in the battery storage. In reverse, charge flows are adjusted in the same way during times with low loads. This is performed not to exceed peak loads.

Medium priority is also given to minimise costs through use of electricity price data. During the winter months the strategy is to use energy arbitrage from the hours with high loads to hours with low loads during daytime.

Minimising electricity quality issues, e.g. fast changes in voltage or fast changes in load and production is not included at the present, but high-resolution measurements over a longer period of time will show if this function needs to be included.

Through smart control of charge and discharge of the battery storage, maximum cost-efficient usage of the power grid from the user's point of view is achieved. This control is facilitated through the existing energy arbitrage and functions for controlling the self-consumption.

6.9 Discussions about the market development for IEM solutions

From the analyses, presented in chapter 5, it is difficult to see a singular development of the market for IEM solutions. Much will be determined by the development of local solar energy production and its connected energy storage. The development will be faster if local solar energy production will continue to be patronised through tax incentives and with investment support, simultaneously with reductions of the cost for battery storage. A similar situation applies if the interpretation or changes in the network concession regulations entails a freer way to transport electricity between buildings, e.g. within a residential building area.

The development of the market for battery storage is a driving force for the implementation of IEM solutions as well, since the value of the battery suppliers' offer increases if the also offer smart control, for improving the customers' profitability. In addition, stand-alone AI (Artificial Intelligence) suppliers may develop more general solutions for control of local energy systems. Such a development, especially if there is a simultaneous development towards standardised open interfaces, should of course accelerate the development further.

Another factor, that could affect the development in the long term is if it became profitable for property owners to offer their flexibility to the energy market actors. The need for such flexibility increases when there is more wind and solar energy production in the system. The basic functionality of the IEM solutions is to control energy flows, which makes such systems very suitable for automation of flexibility on demand.

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