Intelligente flexibiliteit door geïntegreerde hybride opslagtechnologieën

FLEXINet

Public Yearly Progress Report
Period covered
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Het project is uitgevoerd met Topsector Energie subsidie van het Ministerie van Economische Zaken en Klimaat, uitgevoerd door Rijksdienst voor Ondernemend Nederland. De specifieke subsidie voor dit project betreft MOOI-subsidie ronde 2020.

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1 Summary of the principles and the objectives of FLEXINet and its cooperating parties (beneficiaries)

Project Title
Intelligent flexibility through integrated hybrid storage technologies ("FLEXINet")

Objective
The objective of FLEXINet is to develop an integral smart system for the intelligent and integrated control and implementation of hybrid energy storage technologies in the built environment. The smart system will improve the flexibility and sustainability of energy supply (via solar PV) through underground power electronic conversion technology and by combining stationary lithium-ion battery storage, sea salt batteries, electric vehicle charging with vehicle-to-grid technology and thermal energy storage. FLEXINet integrated control strategy for hybrid energy storage will be validated in two living labs.

Outcome
FLEXINet follows a research model that consists of 4 layers: 1) Flexibility-enabling hardware, 2) Integration, conversion and smart control, 3) System flexibility and Living Labs, and 4) Social acceptance and Learning community. The hybrid energy storage technologies that are being developed in layer 1 will be integrated in arrangements for homes and utility buildings, to make the heat and cooling facilities more sustainable and to integrate renewable energy sources and electric vehicles. The smart solutions developed in layers 2 and 3 improve the flexibility and sustainability of electricity supplies by combining stationary battery storage, reused batteries, electric vehicle charging, vehicle-to-grid technology and flexible heat pumps and storage. We strive for the most complete, integrated and validated solution that is attractive to users who are further involved in layers 3 and 4. The end result of the project is an integral smart system for the intelligent and integrated control and implementation of hybrid energy storage technologies in the built environment.

Activities
FLEXINet consists of four interlinked layers. The activities belonging to the first layer of Flexibility-enabling hardware concern the development of innovative low-cost and high-energy battery chemistries and power electronics for hybrid energy storage systems, including the design, development and testing of prototypes. In the second layer, the activities concern the design, integration and smart control of an underground heat storage system, the development of a life-extending battery optimization, the design and testing of a generic and open-source EMS platform and the development of intelligent hybrid EMS algorithms. Later these systems in the System flexibility and Living Labs layer lead to new services and revenue models for reliable networks. Here in this layer, the demonstration, testing and validation of the FLEXINet solution is also done (TRL4-6). In the fourth layer, Social acceptance and learning community, the activities concern the investigation of social acceptance and knowledge dissemination. In this way, we offer a complete and integrated solution to exploit the potential flexibility of the built environment through hybrid energy storage systems.

2 Description of the activities performed, the results achieved per milestone, the bottlenecks and the perspective regarding application; Other issues (<1 page)

R1 - Innovative battery technology

A first pack with silicon anode cells was produced. Si-anode cells have been designed, produced and shipped by LeydenJar to VITO for characterization and testing. The next step is final tests on the pack level at VITO to obtain further data on how the cells function in a pack. Heliox has selected the Battery pack for underground usage and is available (CTS 400V 50Ah LFP Battery). It is now being integrated with the power electronics for the demo sites. DrTen worked on New carbon polymer electrodes for the sea alt batteries. Various new cell configurations were further developed including a so-called triolyser system that enables the production of hydrogen as a side product.

R2 - Power electronics for hybrid energy storage systems

For the bidirectional inverter for the seasalt battery, Dr.Ten has followed 3 R&D paths: 1) Adjustment bi-direct Multiplus in wider V-window via external IBM-Nodered which has proven to work stably at GV with different protocols. 2) Standard bi-direct Multiplus with extra PV coupling / UPS function for seasalt battery. 3) Development of prototype inverter with switch / microprocessor / gridtie from scratch which has proven to work in the lab, though scale-up in customized PCB is still a challenge. For PRE, the design for the underground has been made and once all parts have been received especially the battery pack, assembly and testing of the charger will begin. TU Delft has investigated various cooling methods namely soil-based cooling, air vent-based cooling and liquid cooling. TU Delft has developed a DC//DC power electronic lab proof of concept for EV charging to demonstrate alternative cooling methods using heatpipe and air-cooled fins. The converter is functional and can carry out 10kW power using forced air convection. The concept that will be demoed in GV with TU Delft, PRE is based on the air cooling and central vent. DCO's first prototype of the battery storage converter (11kW) has been tested and it is functional. The BMS board/software is under test in TGV. The converter and the BMS have been combined with an 8kWh battery system for testing and development.

R3 - Heat storage integration

Borg installed a thermal energy storage system and a heat pump in one of the houses of The Green Village. The system was tested for specific use cases, but due to hardware and software limitations (missing interconnectivity), external improvements were required. To support Borg, Delft University of Technology has been developing a customer energy manager (CEM) to connect the thermal energy storage and the heat pump with the other devices of the multi-carrier energy system and the energy management system (EMS) using the S2 protocol. On the other side, Dr. Ten will install a vapour latent heating unit in a different building to evaluate how this device can use the change in concentration of salts as a means to store and provide thermal power through ventilation systems. This device will be tested independently.

R4 - Life-extending battery optimization

VITO and Recoy have collaborated so that the behaviour of K-STAR battery has been monitored, a.o. based on Recoy's typical use profile. A model of the battery pack has been developed and validation tests have been done. The architecture of integration of VITO's degradation analysis with Recoy's optimization models has been almost completed. Dr Ten has worked on the further development of a BMS chip that enables the protection of the battery. Besides it has come to a smart MPPT EMS coupling that is going to be tested at the Green Village.

R5 - Generic and open-source EMS platform

PRE has designed and produced a prototype of the controller. It is currently working with a V2G charger (to control solar input, EV charging, and battery) for testing and validating the controller. By implementing the S2 protocol, the controller is linked to CEM in Result 6. Dr.Ten has done testing of various hybrid lithium seasalt systems and is further running. Both parallel and serial configurations are under research. Also, more research is being done to see if supercapacitive seasalt and seasalt batteries could act as a hybrid. Furthermore, attempts are set to see if a seasalt battery could charge a lithium battery of an e-bike in wireless mode.

R6 - Intelligent Hybrid EMS

The optimization algorithm developed by TU Delft for the EMS can now use the physics-based ageing models for 24-hour operation planning for various cathode chemistries such as NMC and LFP. The thermal storage, EV and stationery lithium-ion battery can be controlled in an integrated way. New features added to the EMS algorithm are Improved infeasibility handling, rolling horizon operation, warm-starting for faster convergence and small modelling improvements. Customer Energy Manager (CEM) is developed in RUST programming language using the S2 protocol with the following essential features: CEM has been successfully tested on the TUD server with multiple RMs. CEM can send the setpoints simultaneously to the multiple connected RMs and receive feedback (measurement) data from the multiple RMs concurrently. CEM can read the setpoints (written by EMS) from the SQL database and send it to connected RM using FRBC.Instruction message. Dr. Ten has evaluated the structure from Github (TNO) for S2 and integrated it to check the messages that are in phyton/into Node-Red so it runs asynchronously. Consolidation of sensor data into a Json on Node-Red and implementation of the Web sockets connection code has been done as well.

R7 - New services and revenue models

The Delft University of Technology studied the role of energy storage to provide flexibility to low-voltage distribution systems. A correlation between different ancillary services and energy storage systems allowed to determine the most suitable ancillary services to be deployed with household-level multi-carrier energy systems comprised of a PV system, battery, thermal storage and heat pumps. It was demonstrated that, without storage, the PV system can cause overvoltages in the low-voltage distribution network in summer, while the heat pumps can lead to undervoltages during winter. These congestion issues can be addressed by coupling the PV and heat pump with electric and thermal energy storage units, even in non-coordinated conditions. Nevertheless, coordinating the energy storage resulted in a more flexible and robust grid. This way, peak-shaving and power curtailment resulted as the most straightforward ancillary services to implement in the Dutch energy market context. It was also proved that both services can be performed in power exchange conditions such that the congestion on the grid is reduced, but the profitability of the system is not consistently affected, resulting in possible business cases to be studied together with Emmet Green.

R8 - Living labs

The Delft University of Technology / The Green Village has worked during this year of the project mainly on the last preparations and first instalments of the test setups. We supported Dr Ten with the installation of the Sea Salt Battery and the first initial run tests. Recoy has installed their home battery and is ready for testing comparing the VITO lab results with a setup in a residential house. PRE is finalizing the underground battery documentation and a location at The Green Village for the setup has been prepared, planned installation in Q3 2024. We supported TU Delft with the connection to the Borg setup. DC Opportunities has been testing successfully with their second-life car battery. HET as a scale-up location in Hilversum has started to draw up the user agreement process with the different partners of the consortium. Using The Green Village template.

R9 - Social acceptance

TU/E has researched the social factors that are hindering and facilitating acceptance of technologies and based on that a scientific paper was published on how acceptance comes about in the context of energy transitions. Besides it has organised co-production workshops with stakeholders from the Green Village to include wishes into the design process of Flexinet partners. In collaboration with HET, a socio-economic analysis was done to understand what possible upscaling scenarios for flexibility technologies are possible outside the Green Village context. The research on possibilities for a local district company has been finished and needs to be tested in a real-life context. These scenarios are being presented in the form of a survey and carried out in the HET context.

R10 - Learning Community and Dissemination

For the first time, the FLEXINet learning community organised a workshop specifically for energy cooperatives. This was very successful in reaching the target group with around 100 participants in the room. Although FLEXINet cannot yet offer market-ready solutions for hybrid storage in the district; this afternoon offered a good broad overview of the playing field and preconditions. Special attention was paid to integration into society and acceptance of people. As a follow-up, energy cooperative HET is setting up a Community of Practice to accelerate the application of hybrid storage in the neighbourhood with like-minded people.

3 Description of FLEXINet's contribution to the objectives of the subsidy scheme (MOOI)

Main innovation theme	Innovation theme (Innovatiethema)	Results
1. Further development of natural gas-free arrangements and supporting processes/services	1. Development of integral arrangements for renovation	2,3
	4. Smart energy use in/between buildings by users, smart grid	5,6, 7,10
2. Making the (collective) heat and cold supply more sustainable	5. Collective heat and cold supply	3
3. Solutions for a reliable, affordable and fair electricity supply	6. Flexibility of/for the energy system (in the built environment)	1-10
	7. System design for the electricity system in the built environment	5,6,8,10
	8. Local flexibility for the overall electricity system	6,7.9

(1) Further development of natural gas-free arrangements and supporting processes/services.

- Intelligent and integrated energy management hardware and control – FLEXINet will develop intelligent and integrated control algorithms to increase the flexibility of electricity and heat supply through hybrid energy storage and develop a hardware controller to interface with various power generation/conversion devices. The EMS will implement a multi-objective optimization to reduce/eradicate the use of natural gas by using heat pumps with thermal storage and solar collectors, increase the use of renewables, improve grid integration and offer ancillary services. *Results: Algorithms, Controller (product) demonstration*

- (Underground) power conversion cabinet - Space is often a challenge for the placement of batteries and hardware. We develop the FLEXGRID-PLUS solution, an invisible (underground) box that contains the batteries, power electronics including solar MPPT converter, inverters, and EV chargers for controlling the hybrid storage system. We also develop power electronics for the efficient use of discarded traction batteries that get a second life as a stationary energy storage system and to connect seasalt batteries to the grid. *Results: FLEXGRID-PLUS (product), demonstration*

(2) Making the (collective) heat and cold supply more sustainable

- More sustainable heat supply through thermal storage, heat pipes and heat pumps - FLEXInet will develop an underground heat buffer connected through flexible heat pumps and heat pipes. The buffer works with an intelligently controlled weather and demand forecasting model to control the behaviour of the connected energy sources. We will also develop seasalt-based vapour heating unit as a means to reduce the use of natural gas. *Results: Algorithms, thermal buffer (product), vapour heat unit (product), demonstration*

- Social acceptance and experience of flexibility - We investigate social factors and draw up a business case for the investment and financing and build a cooperative neighbourhood organization as a basis and management organization for the hybrid storage facilities. The basis for the business case is an investigation into the circumstances under which users in the neighbourhoods want to make flexibility available in which both financial and non-financial costs and benefits are considered. *Results: Social factors and optimization of willingness to participate, business model*

(3) Smart solutions for the reliability, affordability and fairness of electricity supply

- Novel energy storage technologies - to increase the flexibility of hybrid energy storage, we will improve sea-salt battery technology; develop silicon anodes to increase the energy density of lithium-ion batteries; study the ageing behaviour and develop optimization algorithms to improve the lifetime of Li-ion cells. *Results: sea-salt battery (product), silicon anodes (product), Algorithms, demonstration*

- New services and revenue models for hybrid storage. We evaluate the possibility of using demand management to enable the aforementioned storage technologies to reinforce each other. We will also design transactional energy solutions, based on peer-*to-peer* delivery, through the potential complementary effect of using hybrid storage technologies. Finally, we determine guidelines and requirements for the provision of additional services to the grid (DSOs/TSOs) through hybrid energy storage in the built environment. *Results: Algorithms, simulations, guidelines, business models*

- Learning community and dissemination - As an integral part of the project, we ensure an adequate link between innovative technologies that support the energy transition and the knowledge and skills needed to implement these technologies in practice. *Results: Information, training materials, guidelines*

4 Spin off inside and outside the sector

Not applicable yet.

5 Overview of the project's open access (public) publications and where to find/obtain them

FLEXINet project website: https://www.tudelft.nl/en/eemcs/flexinet/learning-community

Journal & Conference Articles

- Slaifstein, D., Alpizar Castillo, J., Menendez Agudin, A., Ramirez Elizondo, L., Chandra Mouli, G. R., & Bauer, P. (2023). Aging-Aware Battery Operation for Multicarrier Energy Systems. In *Proceedings of the IECON 2023- 49th Annual Conference of the IEEE Industrial Electronics Society* (Proceedings of the Annual Conference of the IEEE Industrial Electronics Society). IEEE. https://doi.org/10.1109/IECON51785.2023.10312455
- Alpízar-Castillo, J., Ramírez-Elizondo, L. M., & Bauer, P. (2024). Modelling and evaluating different multi-carrier energy system configurations for a Dutch house. *Applied Energy*, *364*, 123197. doi.org/10.1016/j.apenergy.2024.123197
- J. Alpízar-Castillo, L. Ramírez-Elizondo and P. Bauer, " The Effect of Non-Coordinated Heating Electrification Alternatives on a Low-Voltage Distribution Network with High PV Penetration," 2023 IEEE 27th International Conference on Compatibility, Power Electronics, and Power Engineering (CPE-POWERENG), Tallinn, Estonia, 2023, doi.org/10.1109/CPE-POWERENG58103.2023.10227394.
- S. J. Kouwenberg, J. Alpízar-Castillo, L. Ramírez-Elizondo and P. Bauer, "Insight into the Characterization of Sea-Salt Batteries," 2023 IEEE 27th International Conference on Compatibility, Power Electronics, and Power Engineering (CPE-POWERENG), Tallinn, Estonia, 2023, doi.org/10.1109/CPE-POWERENG58103.2023.10227412.

Presentations

- 11 April 2024 - Workshop: Het realiseren van hybride energieopslag in de wijk
- 3 October 2023 - Workshop: Realizing Hybrid Storage
- 4 April 2023 - Workshop: Acceptance of the energy transition and related technologies