VINPOWER Vaasa innovation platform for future power systems : Final report (summary)

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VINPOWER

Vaasa innovation platform for future power systems

Final report (summary)

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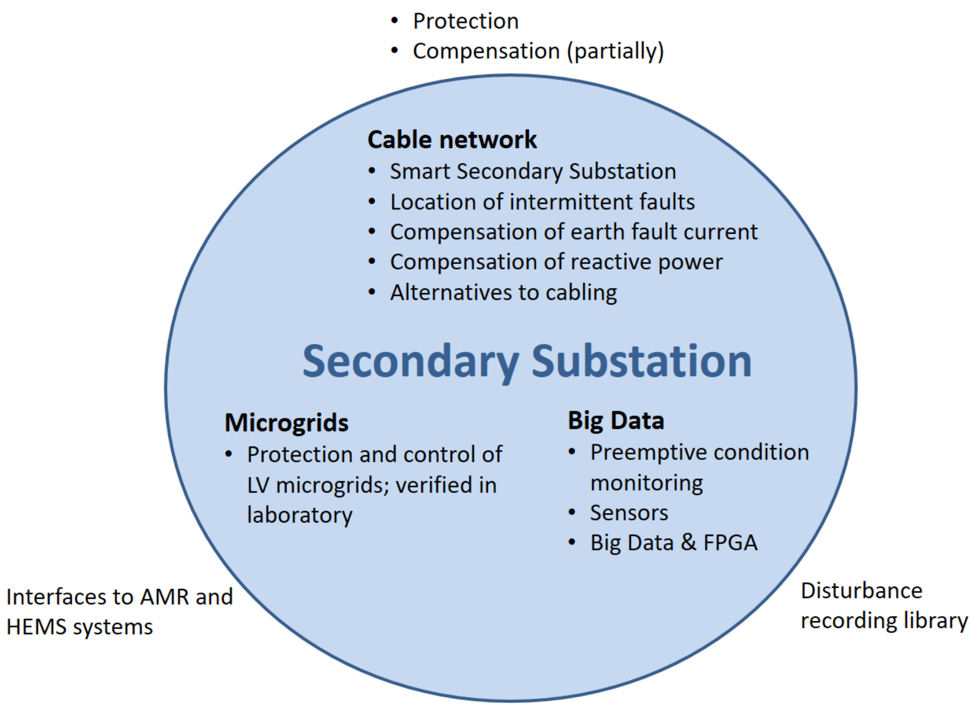
University of Vaasa



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2014–2020

Abstract

The main objective of the project was to develop smart grid related expertise within the University of Vaasa. While the parallel project (Smart Energy Systems Platform – SESP) focused on the development of the physical research facilities, VINPOWER contributed to the development of the RDI environment by increasing expertise in the selected research areas. Moreover, the project aimed at delivering new knowledge and concepts for the industries, improved cooperation between the project partners and promotion of new technology for enhanced reliability of electricity distribution networks.

The research work was divided into four work packages, WP1 Cabled medium voltage networks, WP2 Microgrids, WP3 Big Data Applications, and WP4 Dissemination and networking. In WP1, technologies for fault location, earth fault compensation and reactive power compensation were developed, and concepts for future secondary substation were outlined. In WP2, selected functionalities of microgrids were analysed, and protection and control related functions were developed and demonstrated. The third WP examined how Big Data and FPGA technologies could be utilized for network operation and maintenance needs. A disturbance recording library, intended for national use, was also developed. WP4 complemented the project by dissemination and networking.

The main result of the project is the development of the Smart Grid expertise and innovation environment at the University of Vaasa. This provides better basis for future research projects, both nationally and internationally. Examples of more tangible results are the solutions to the compensation of cabled MV networks, developments in protection and control functions of microgrids, the national disturbance recording library, and the comparisons produced in the real world case study of alternatives to improve the reliability of MV feeders. According to the self-evaluation, carried out by the steering group, workshops were the highlight of the project, enabling vivid discussions and promoting networking of all participants.

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Foreword

VINPOWER was a research project lead by the University of Vaasa. The responsible director was Kimmo Kauhaniemi, and Lauri Kumpulainen acted as the project manager. Majority of the funding came from the European Regional Develoment Fund through the Regional Council of Ostrobothnia. Finnish Energy's Electricity Research Pool and a number of distribution network operators as well as manufacturing companies provided the vital private funding and very important contribution by actively sharing their expertise in the steering group. Antero Martimo (the starting phase of the project) and Petri Hovila (the remaining phase) served as chairmen of the project in a constructive way.

The organisations that provided funding for the project and their representatives in the steering group are presented in the table below.

Company / Community	**Representative in the steering group**
ABB Oy, Medium Voltage Products	Petri Hovila
Arcteq Relays Oy	Tero Virtala
Emtele Oy	Ville Sallinen
Ensto Finland Oy	Tommi Kasteenpohja (Markku Wederhorn)
Finnkumu Oy	Seppo Bragge
Helen Sähköverkko Oy	Mika Loukkalahti
LE-Sähköverkko Oy	-
Maviko Oy	-
Netcontrol Oy	Marcus Biström
Alfen Elkamo Oy Ab	Markus Kekolahti (Jouni Aaltonen)
Tampereen Sähköverkko Oy	-
Turku Energia Sähköverkot	Antti Nieminen
Vaasan Sähköverkko Oy	-
VAMP Oy	Juha Hirsimäki
Wapice Oy	Veli-Pekka Salo
VEO Oy	Ari Pätsi
Sähkötutkimuspooli (Adato Energia Oy)	Antero Martimo
The Regional Council of Ostrobothnia	Johanna Leppänen
University of Vaasa	Kimmo Kauhaniemi

Thanks to all the participants!

On behalf of the authors,
Lauri Kumpulainen

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1 The objectives and the structure of the project

The main objective of the project was to increase the expertise of the University of Vaasa in selected areas of smart grid technology. The project also aimed at developing solutions to topical research questions of the industry, and increasing the cooperation between project partners. The project scope covered the whole electricity distribution network, from primary substation down to the customers, even to home automation systems.

The project was divided into four work packages of which three were research oriented, and the last one was for dissemination and networking. Each WP was included several tasks as described below.

WP1: Cabled medium voltage networks
- T1.1 Improved solutions to the protection and fault location of long MV cable feeders
- T1.2 Alternative solutions for advanced security of supply
- T1.3 Compensation of the earth-fault current and compensation of reactive power
- T1.4 Smart secondary substations

WP2: Microgrids
- T2.1 Functional analysis of microgrids
- T2.2 Development of new control and management functions
- T2.3 Integration to Smart Home

WP3: Big data applications
- T3.1 State of art review
- T3.2 Applications in power systems
- T3.3 National disturbance recording and field test data library
- T3.4 FPGA based solution for local data processing

WP4: Dissemination and networking
- T4.1 Communication
- T4.2 Workshops
- T4.3 International networking
- T4.4 Shared data store and web pages

2 Results

2.1 WP1: Cabled medium voltage networks

T1.1 Improved solutions to the protection and fault location of long MV cable feeders

The main result of this task was the development of two promising principles of cost-efficient methods for the location of intermittent faults. However, the validation of these methods relies on simulation studies and limited field test data. More field data based verification is needed.

In this task, also a state-of-the-art type study on the challenges and possible solutions related to earth-faults on long MV cable feeders was produced.

T1.2 Alternative solutions for advanced security of supply

Motivation for this task came from two challenges: (1) The repair time of MV underground cables is long, especially in harsh winter conditions. (2) Undergrounding is not always economically justified in sparsely populated regions.

In this task, two separate reports were produced. The first one was a literature survey on available options to increase reliability of MV distribution. Along with this survey, a statement, suggesting changes to the current regulation, was sent to the national Smart Grid Working group.

The second part of this task was an extensive case study which compared the impact of several alternative technologies (battery energy storage, 1 kV distribution system, mobile and fixed reserve power, network automation and cabling) on real MV network. The impact of current regulatory incentives were included in the economic calculations. The summary of the economic comparison is illustrated in Figure 1.

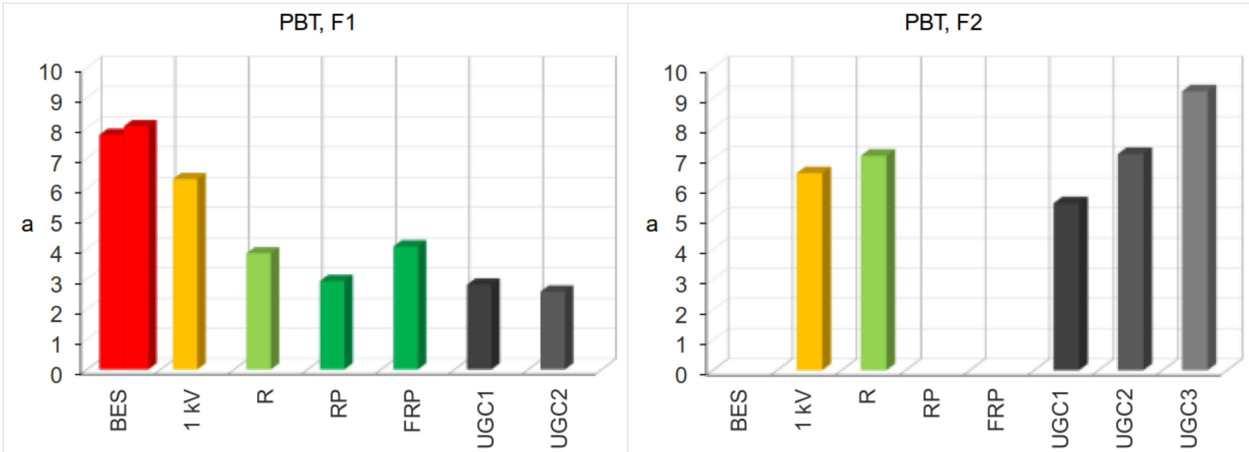


Figure 1. Payback times of different technologies on two examined MV feeders. (BES = battery energy storage, R = Reclosers, RP = reserve power, FRP = fixed reserve power, UGC = underground cabling). (Lågland et al. 2019)

T1.3 Compensation of the earth-fault current and compensation of reactive power

Extensive cabling of MV networks increases both reactive power produced by the feeders and earth fault current. This has created an urgent need to compensation solutions, so that high costs due to exceeding reactive power limits can be avoided, and earth fault protection operates correctly.

In Ojala's study (Ojala 2018), a concept for distributed reactive power control for rural networks was developed. The concept consists of monitoring, measuring, control and protection functions, including hardware solutions.

In another study (Memon 2019), two methods for reactive power compensation at the MV level were examined by simulations. The first method was to place a STATCOM device at the primary substation. The central STATCOM provides dynamic reactive power compensation at MV side of HV/MV substation transformer in all load conditions. It can generate or absorb a fixed amount reactive power based on local real-time reactive power measurement or based on set-points of reactive power demand variations at the connection point. For example: it absorbs extra reactive power generated by cables during off-peak load and it generates reactive power during peak load to support voltage regulation.

The second, novel method was to utilize the capability of the converter of a wind power plant for reactive power compensation. For this purpose, a phasor type model of type-4 wind turbine generator was created, which was quite a challenging task. However, the wind turbine generator model (Figure 2) needs further improvements in controller section of the grid-side converter. The converter of the modelled WTG is not able to control its output Q or terminal voltage independently. For this some further development of the model is needed.

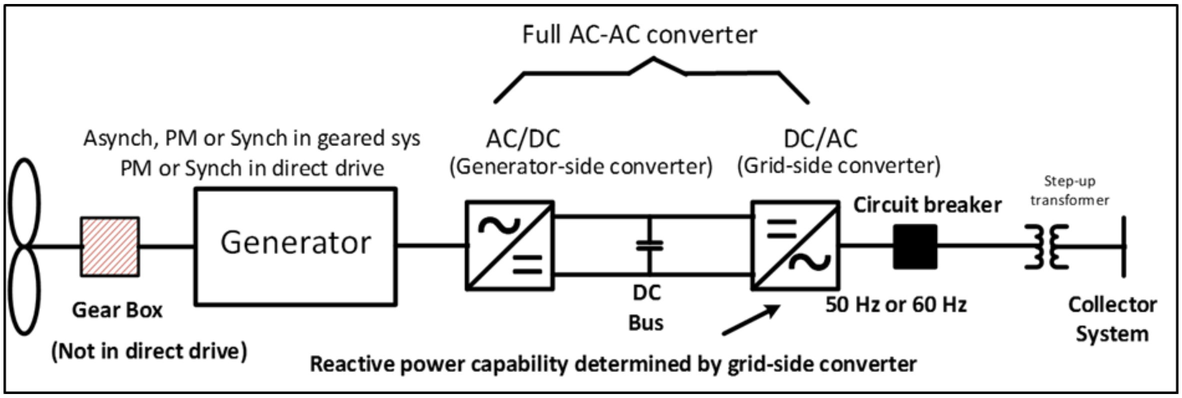


Figure 2. Type-4 Wind turbine generator (Synch Gen and full-scale converter)

Moreover, the operational principles of active earthing were outlined. In the developed method it is not necessary to identify the faulted phase. The method is based on measuring the zero sequence impedance of the network under normal conditions and injecting current into the neutral under fault conditions so that the zero sequence impedance of the network remains the same. Simulation results confirmed the validity of the proposed principles.

T1.4 Smart secondary substations

The concepts for rural and urban smart secondary substations were created largely from the results of two successful workshops. The concepts were planned for near future (2025) and for long term development (2035) including both basic and additional functionality. However, these concepts are still rather loose collections of ideas, and further R&D and cooperation is required.

As a very useful result, the workshops associated with this task have inspired researchers and representatives of industry to start planning further work, aiming at more tangible specifications for future secondary substations.

2.2 WP2: Microgrids

T2.1 Functional analysis of microgrids

This task aimed at detailed descriptions of selected functions of microgrids. The focus of this study was on the following microgrid operation and control use cases: energy management (grid connected and islanded mode), protection, and ancillary services. The primary use cases have been protection and ancillary Services. Figure 3 presents the use case diagram developed in the analysis.

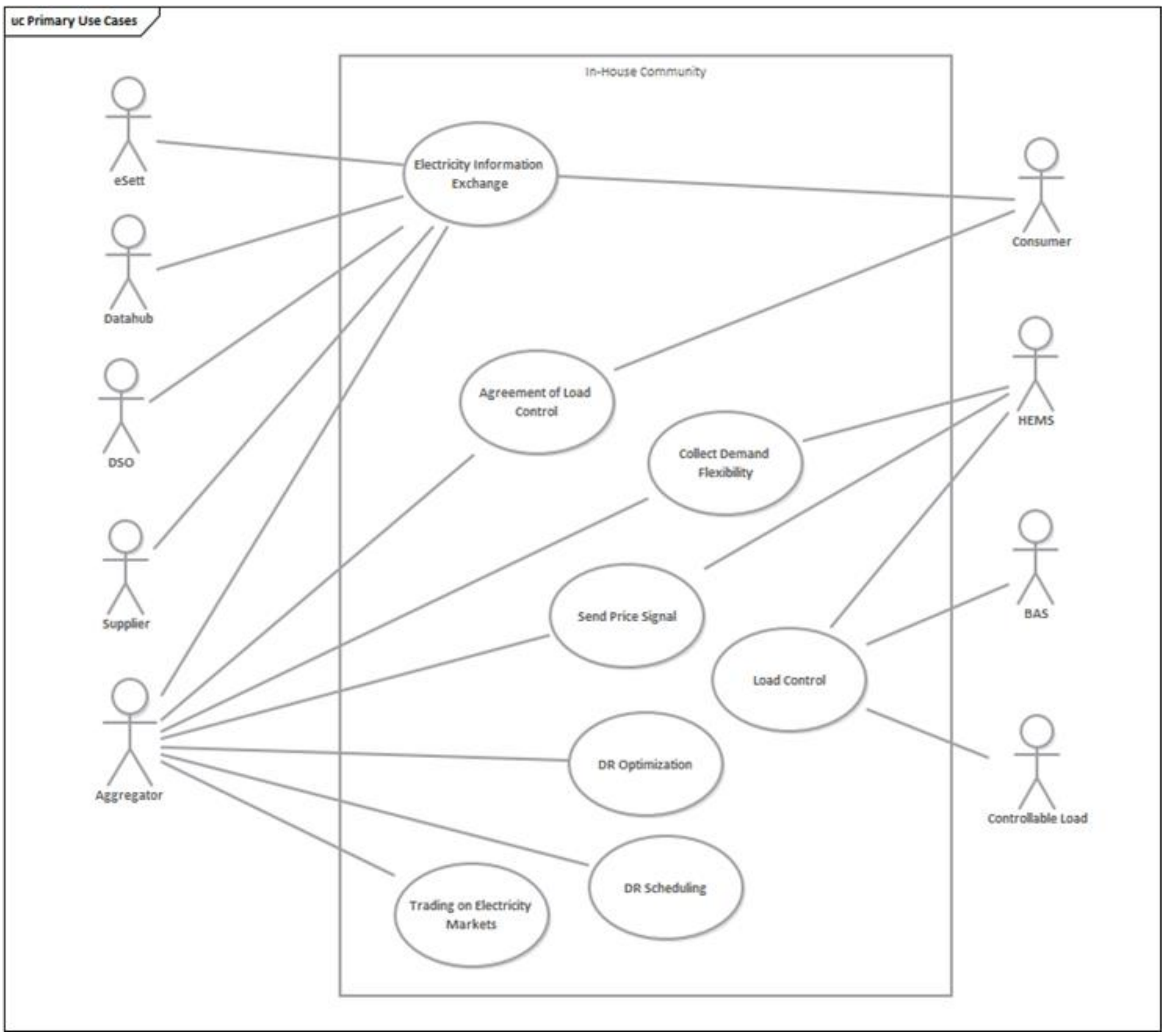


Figure 3. Use case diagram.

Simulation cases were developed according to the developed use cases, utilizing Sundom Smart Grid network model:

- Microgrid Controller functions as software-in-the-loop (SIL)
- Demand response for ancillary services
- Management of reactive power flow, Fingrid's (Q, P) window

The major achievement of this task are the developed microgrid controller functionalities (e.g. the management of reactive power), which have been verified by the simulations based on a real network. The details will reported in a scientific paper "Functional analysis of microgrids and integration of the management system".

T2.2 Development of new control and management functions

In this task, selected microgrid control, protection or management functions were developed and demonstrated. The selected control functions were the following:

- Smooth transition to and from grid-connected and islanded modes
- Activation/deactivation of battery energy storages (Central + parallel with DG)
- Voltage and frequency control with different operation modes

The developed microgrid protection functions:

- Loss-of-Mains (transfer trip), interlocking using IEC 61850-GOOSE (together in steps)
- IEC 61850 based interoperability of IEDs from different vendors (OPAL, VAMP)
- Definite time vs. Inverse definite minimum time (IDMT) overcurrent relay for adaptive protection
- Adaptive OC protection algorithms based on IEC 61850-GOOSE (revision based on new practical results, for example delays obtained by VAMP-OPAL testing)

The operation of the developed functions was demonstrated in the Smart Grid laboratory of University of Vaasa utilizing OPAL-RT real-time simulator and IEC61850 GOOSE communication.

Figure 4 illustrates the demonstrated microgrid islanding functionality.

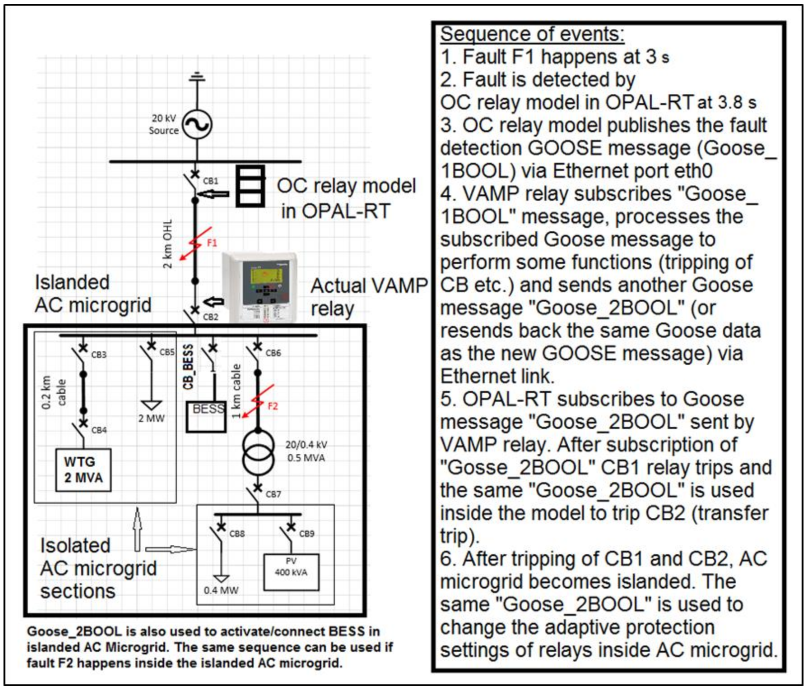


Figure 4. Demonstrated microgrid islanding functionality.

T2.3 Integration to Smart Home

The objective of this task was to propose suitable solutions for integrating the microgrid control system and the whole active network management system to the AMR and Home automation system. The key components of this integration are the following:

- Distribution Automation (DA) system
  - Hierarchical decentralized system
- Distributed Energy Resources (DER)
  - Distributed Generation (DG)
  - Demand Response (DR)
  - Energy Storage (ES)
  - Microgrids

Microgrid Central Controller (MGCC) Interaction with Smart Home was examined. Outcomes:

- Study in the MGC functions point of view
- Analysis: Distribution Management System – MGCC – Smart Home

The detailed results will be reported in the same scientific paper as in task 2.1.

2.3 WP3: Big Data applications

T3.1 State-of-the-art review

A general overview of Big Data and its potential applications in power systems was produced.

T3.2 Applications in power systems

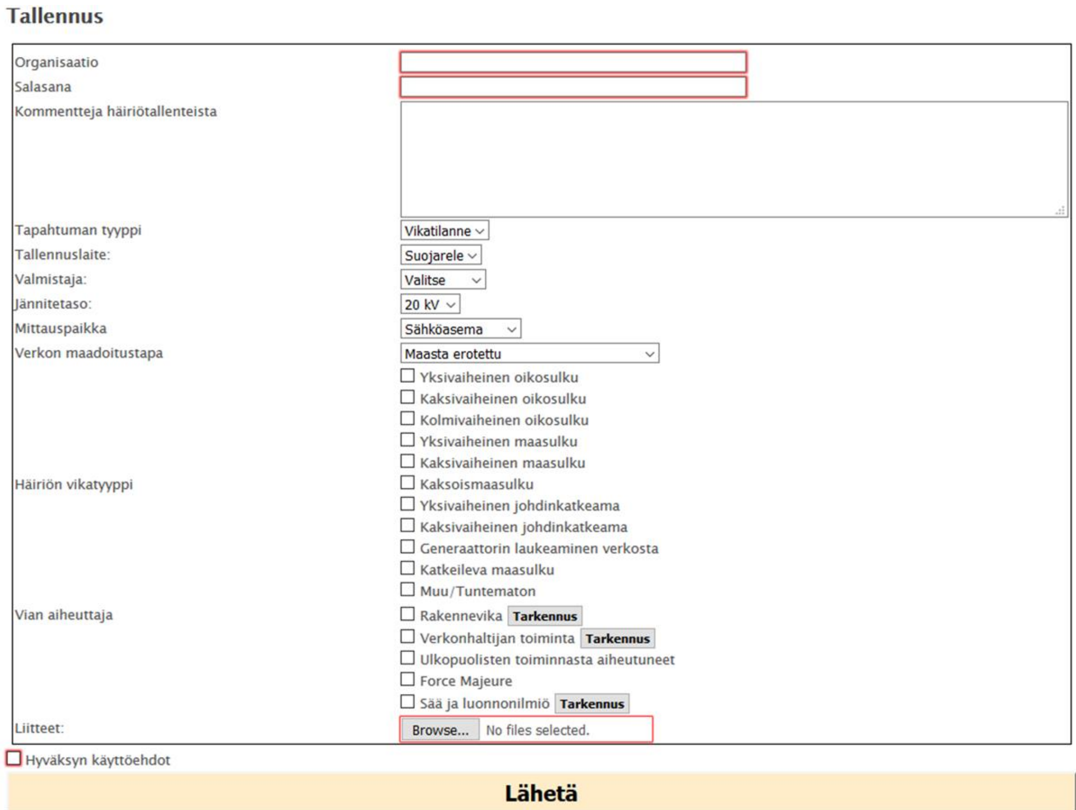
The objective of this task was to develop Big Data based condition monitoring system for MV cables and secondary substations. Identification of developing faults could be possible by measuring partial discharges and analyzing them by applying suitable mathematical methods and patterns.

However, the actual development of such a system could not be achieved. Especially, appropriate signal processing technology could not be found. Instead, a report, "Detection Techniques and Methods for Partial Discharge Measurements", was produced. The report provides a literature review of condition monitoring techniques and methods for MV cables and MV/LV transformer. In the report, different sensing methods and features of partial discharges are discussed.

T3.3 National disturbance recording and field test data library

The objective was to construct a disturbance recording library (data base), including field test data and real fault recordings. The national library will be utilized by network companies, relay manufacturers and universities for research, development and educational purposes. Ease of use (both input and output) of the system was one of the main targets of the development. Figures 5 and 6 give examples of the user interface of the system.

Figure 5. An example of the user interface of the disturbance recording library.


Tallennus

Organisaatio	
Salasana	
Kommentteja häiriötallenteista	
Tapahtuman tyyppi	Vikatilanne
Tallennuslaite:	Suojarele
Valmistaja:	Valitse
Jännitetaso:	20 kV
Mittauspaikka	Sähköasema
Verkon maadoitustapa	Maasta erotettu
Häiriön vikatyyppi	☐ Yksivaiheinen oikosulku ☐ Kaksivaiheinen oikosulku ☐ Kolmivaiheinen oikosulku ☐ Yksivaiheinen maasulku ☐ Kaksivaiheinen maasulku ☐ Kaksoismaasulku ☐ Yksivaiheinen johdinkatkeama ☐ Kaksivaiheinen johdinkatkeama ☐ Generaattorin laukeaminen verkosta ☐ Katkeileva maasulku ☐ Muu/Tuntematon
Vian aiheuttaja	☐ Rakennevika Tarkennus ☐ Verkonhaltijan toiminta Tarkennus ☐ Ulkopuolisten toiminnasta aiheutuneet ☐ Force Majeure ☐ Sää ja luonnonilmiö Tarkennus
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Lähetä

Figure 6. An example of the user interface (input view) of the disturbance recording library.

The disturbance library was successfully designed, implemented and partially also tested. However, due to license issues, the system has to be transferred to a new environment, before it can be opened to wider use.

T3.4 FPGA based solution for local data processing

All the methods studied in this WP utilize measured data with a high sampling rate. Transfer of this data to a central location might be problematic if the communication bandwidth is very limited. FPGA is a special processor architecture with high efficiency and compact size. It enables the computation and processing of the data locally, so that only main characteristics are transferred over the communication channel.

In this task, an FPGA based solution for processing measurement data (IEC61850 Sampled Values from Sundom Smart Grid) was developed and demonstrated. The algorithm was developed in the Matlab and OPAL environments before the implementation into FPGA. The application was able to extract signal features such as frequency and phase.

The most important outcome of this task was the increase of the expertise in the FPGA technology.

2.4 WP4: Dissemination and networking

This work package consisted of the following tasks: T4.1 Communication, T4.2 Workshops, T4.3 International networking, and T4.4 Shared data store and web pages. The main outcome were the three successful workshops, two focusing on secondary substations, and the third one was international, “Nordic Workshop in Power System Protection”.

3 Further work

The title of the project was “VINPOWER – Vaasa innovation platform for future power systems”. From the very beginning it was clear that since the main objective was to increase the expertise of the University of Vaasa in selected areas of smart grid technology, the number of tangible results, ready to be implemented by the industry, would not be very high. However, the increased expertise is a good basis for further studies, both scientifically and from the practical applications point of view.

Several examples of further work, based on the results of this project, can be listed:

- The R&D work related to the location of intermittent earth fault continues, and in the best case it will soon produce an invention disclosure.
- Research on some of the technologies proposed for advance security of supply (e.g. energy storages, microgrids) continues in ongoing and future projects.
- Compensation and earth fault issues have been selected as one of the key expertise areas of the research group Smart Electric Systems (SES).
- Smart secondary substations will very likely be the focus of one work package in the planned large “Digital Grid” project, involving several research organisations.
- Microgrid technology is studied and developed in ongoing projects, and they will stay as one of the research pillars of the SES research group.
- Knowledge about Big Data analytics and data processing will be further utilized in the multinational Future Smart Energy (FUSE) project.
- The national disturbance recordings and field test data library will be converted to another software environment, tested and taken into wider use.
- Work on FPGA technology will continue at the University of Vaasa, in cooperation with other research teams in the School of Technology and Innovations.

4 Reports, publications and presentations

4.1 Reports and scientific papers

T1.1 Voima Improved solutions to the protection and fault location of long MV cable feeders

T1.2 Lågland Case Study_Sähkönsyötön varmuuden parantamisen vaihtoehtoja

T1.2 Lågland CIRED Alternative solutions for advanced security of supply

Lågland, Henry; Kauhaniemi, Kimmo; Kumpulainen, Lauri; Salo, Ari; Leppinen, Jarmo; *Alternative solutions for advanced security of supply*; Proceedings of CIRED 2019, Madrid, 3-6 June 2019

T1.2 Kumpulainen Sähkönsyötön varmuuden parantamisen vaihtoehtoja

T1.2 Kumpulainen Kannanotto Älyverkkotyöryhmälle

T1.3 Ojala Sähkönjakeluverkon loistehon ohjauksen järjestelmäkonseptin suunnittelu

Ojala, M., *Sähkönjakeluverkon loistehon ohjauksen järjestelmäkonseptin suunnittelu*; diplomityö, Vaasan yliopisto, 2018.

T1.3 Memon Application of STATCOM for Q-compensation in distribution networks with cables

T3.2 Kumar Detection-Techniques-and-Methods-for-Partial-Discharge-Measurements

T3.3 Kankainen Häiriötallennekirjaston käyttöohje

T4.2 Voima 1. älymuuntamotyöpajan kooste

T4.2 Voima 2. älymuuntamotyöpajan kooste

T4.3 Voima Nordic Workshop kooste

Expected scientific papers (to be submitted late 2019/early 2020):

- Amir Farughian: “Intermittent earth fault passage indication in non-effectively grounded distribution networks”
- Katja Sirviö: “Functional analysis of microgrids and integration of the management system”

4.2 Presentations

T1.1 Slides Farughian Methods for locating intermittent faults

T1.2 Slides Lågland Case Study Sähkönsyötön varmuuden parantamisen vaihtoehtoja

T1.3 Slides Ojala & Pätsi Loistehon hallinta jakeluverkossa (VEO)

T1.3 Slides_Memon_Reactive power compensation

T1.3 Slides Farughian Compensation of the earth-fault current

T2.1 Slides Sirviö Functional analysis of microgrids and 2.3 Integration to smart home

T2.2 Slides Memon AC Microgrid functions using IEC 61850 communication

T3.1 Slides Kumar Review of potential Big Data applications for power systems

T3.2 Slides Kumar Big Data Applications in Power Systems

T3.3 Slides Kankainen Häiriötallennekirjasto

T3.4 Slides Mekkanen_FPGA applications for local data processing

T4.2 Slides Voima 1. Älymuuntamotyöpajan kooste

T4.2 Slides Voima 2. Älymuuntamotyöpajan kooste

T4.3 Slides Voima Nordic Workshop kooste

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