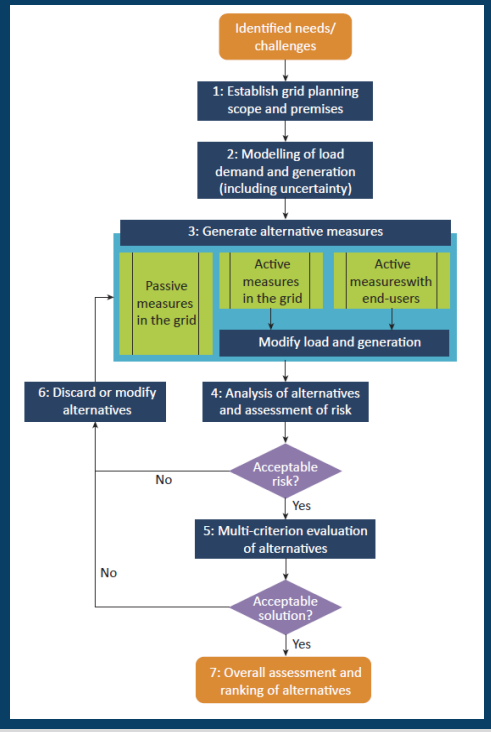
Selected CINELDI Results 2019

CINELDI result:
Active distribution grid planning – draft framework (WP1)

Challenge and objective:

- More variability and new uncertainties due to e.g. variable distributed generation and electrification of transport, together with new active grid operation technologies, call for new planning methodologies.



Work performed:

- Synthesis of previously performed review of needs and gaps and workshop with project partners
- Adaptation and extension of traditional grid planning framework in the Norwegian handbook on power system planning (Planboka) and active distribution grid planning framework by CIGRE WG C6.19

Significant results:

- A framework explicitly accounting for active grid planning measures, structured in seven steps
- Overview and examples of relevant methodology that can be incorporated at different grid levels (MV, LV) for each of the steps

Impact for distribution system innovation:

- Allows for active grid measures and related technologies to be considered more consistently in distribution system development

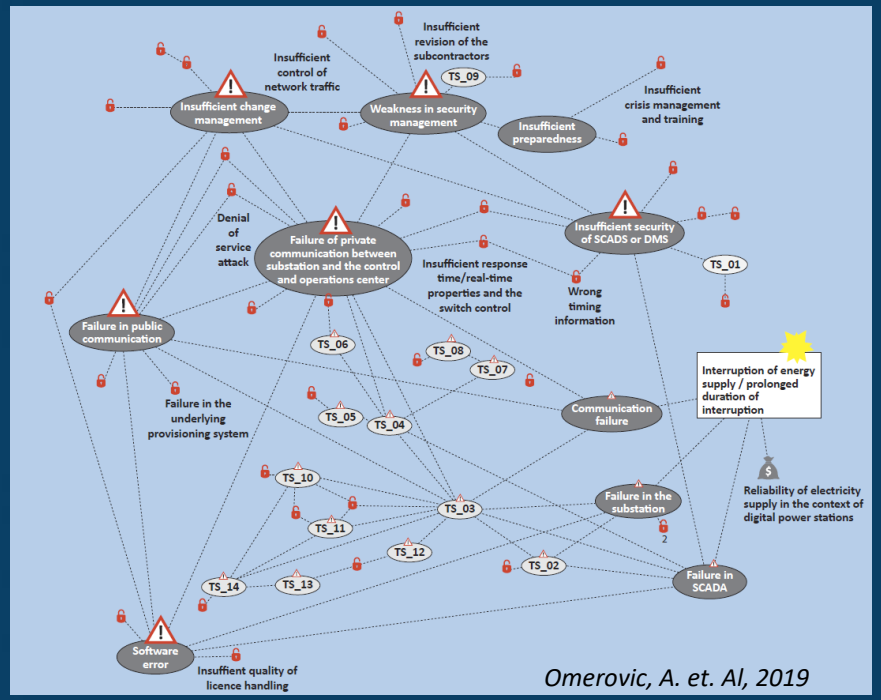
Reference in CINELDI:

- I.B. Sperstad, E. Solvang and O. Gjerde: "Framework and methodology for active distribution grid planning in Norway", PMAPS 2020

CINELDI result: Industrial Evaluation of an Approach to Identification and Modelling of Cybersecurity Risks (WP1)

Challenge and objective:

- Smart grids are characterized by high complexity, uncertainty, dynamics, and interdisciplinarity.
- Digital transformation of the power grids has significantly changed the risk picture.
- The state-of-the-art on cybersecurity risk management is therefore challenged.



Omerovic, A. et. Al, 2019

Work performed:

- Developed a qualitative approach to risk modelling, which accommodates interdisciplinarity and uncertainty.
- A full-scale performance evaluation of an approach to identification and modelling of cybersecurity risks in the context of digital secondary substations.

Significant result:

- Improved understanding of the effects of power grid digitalization on cybersecurity, as well as impacts of cybersecurity on reliability of supply.

Impact for distribution system innovation:

- Decision support for management of reliability of power supply affected by cybersecurity.

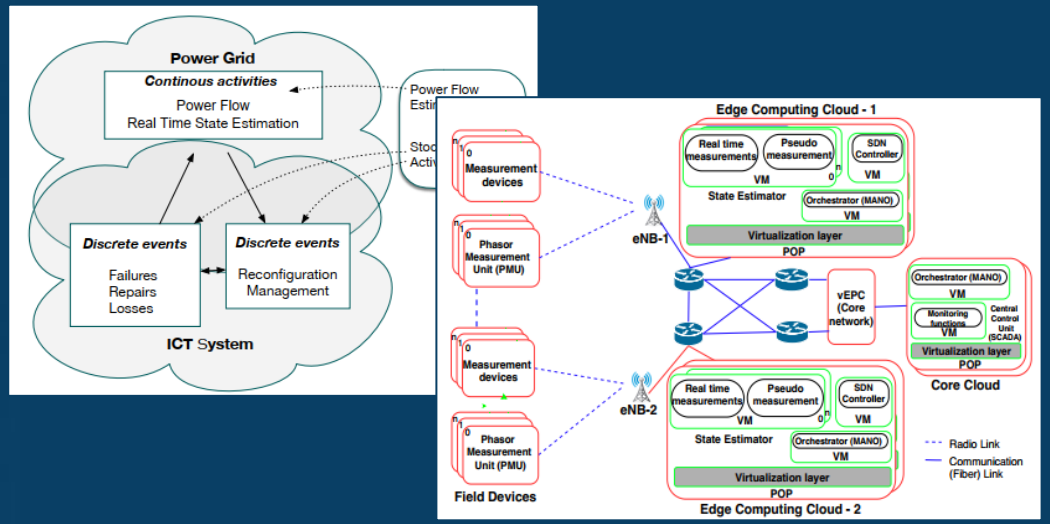
References in CINELDI:

- A. Omerovic et.al.: "An Industrial Trial of an Approach to Identification and Modelling of Cybersecurity Risks in the Context of Digital Secondary Substations", Risks and Security of Internet and Systems: CRiSIS 2019 – Proceedings

CINELDI result: Effect of Communication Failures on State Estimation of 5G-Enabled Smart Grid (WP1)

Challenge and objective:

- The high dependence of power system on Information and Communication Technologies establish new interdependencies and sources of failures that need to be properly analysed.
- A new modelling approach is proposed for analysing the impact of communication failures in a smart grid monitoring scenario, with a specific focus on 5G implementation.



Work performed:

- A stochastic activity network model of the power Cyber Physical System was implemented
- Dependability metrics are analysed through a case study, with different state estimation approaches, rain regions and repair strategies

Significant results:

- Analyses show that the radio channel is the major source of estimation error
- Factors such as fading and rain conditions, may affect the accuracy of state estimation significantly

Impact for distribution system innovation:

- Modelling and simulation of interdependencies between ICT and power system are fundamental in smart grid design
- The close to ideal behaviour of 5G-URLLC enforces the prospect of future adoption for smart grid monitoring

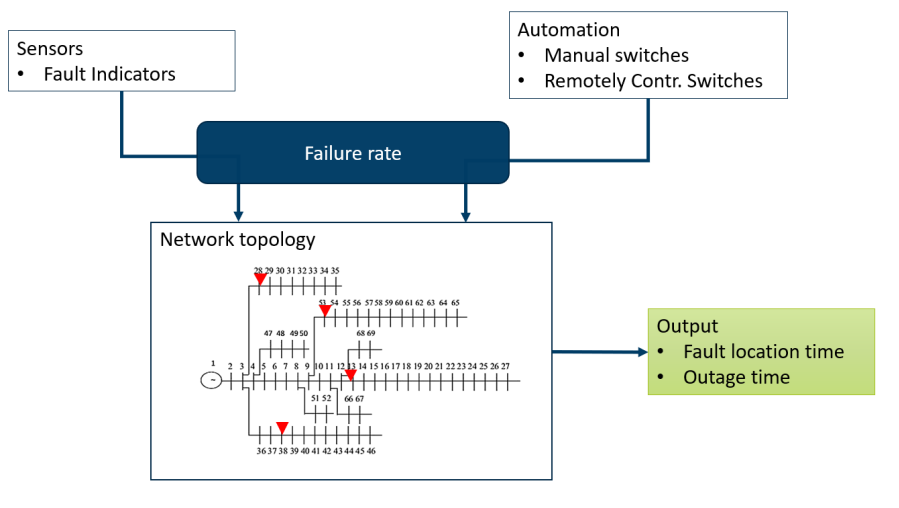
Reference in CINELDI:

- T. Amare, M. Garau and B.E. Helvik: "Effect of Communication Failures on State Estimation of 5G-Enabled Smart Grid", IEEE Access

CINELDI result: Distribution Grid Fault Location Based on Entropy Minimization (WP1)

Challenge and objective:

- The small number of monitoring devices in distribution systems require special methods in managing fault conditions, due to the high level of uncertainty of the state of the system and the measurement data.
- These methods should be able to take into account these uncertainties in fault location to minimize outage times.



Work performed:

- A novel method for fault location is proposed, based on the concept of entropy minimization
- The method is tested on different distribution network topologies, with different levels of automation

Significant results:

- Analyses show the capability of the method:
  - to support operators in optimal strategies for fault location in MV grids
  - to conduct reliability analysis of the system

Impact for distribution system innovation:

- The algorithm demonstrates a computational efficiency which opens a potential for usage in planning of optimal placement of sensors based on iterative heuristics

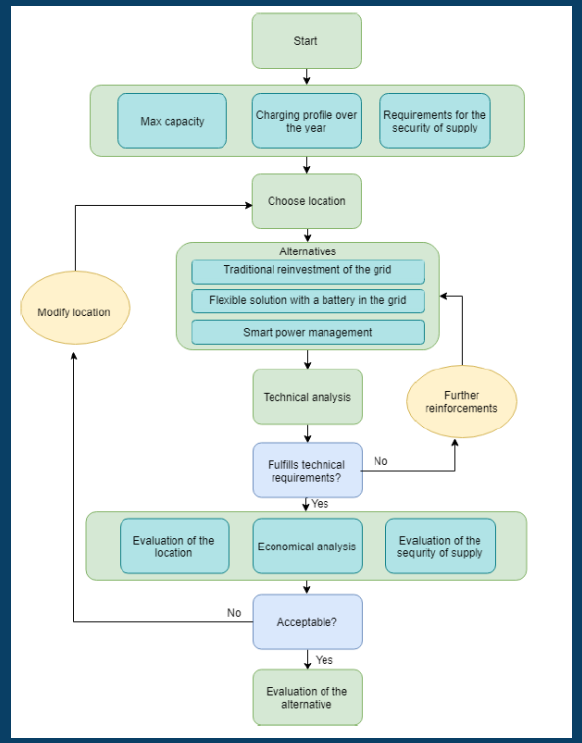
Reference in CINELDI:

- M. Garau and B.E. Helvik: "Distribution Grid Fault Location Based on Entropy Minimization", under preparation to be submitted to a journal

CINELDI result: Case study on planning a fast charging station (WP1)

Challenge and objective:

Electrification of the transport sector requires a secure and predictable charging network. The grid planning framework has been adapted and a case study on optimisation of the location of fast charging stations in the grid has been carried out.



Work performed:

- Suggested an adaption of the traditional grid planning framework to enable planning of fast charging stations, aiming to optimise the location taking available grid capacity as well as traffic considerations into account.
- The method is tested in the distribution grid of Eidsiva Nett.

Significant results:

- A case study visualsing how planning of fast charging stations, able to analyse both traditional grid reinforcement, battery storage and smart power management alternatives, can be carried out.

Impact for distribution system innovation:

- Decision support to aid in the selection of location and grid planning for fast charging stations to optimise costs.

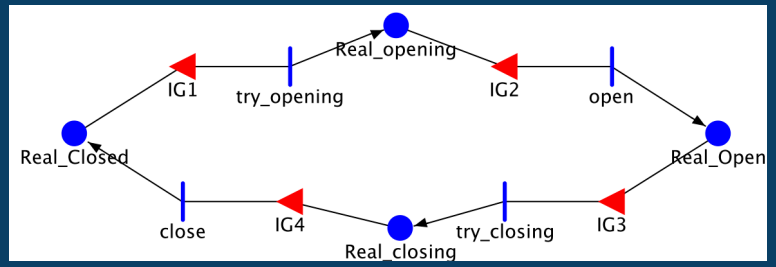
Reference in CINELDI:

- N. Skyttermoen: "A Method for Planning a Fast Charging Station. Applied to the distribution grid of Eidsiva Nett", Master's thesis, NTNU 2019

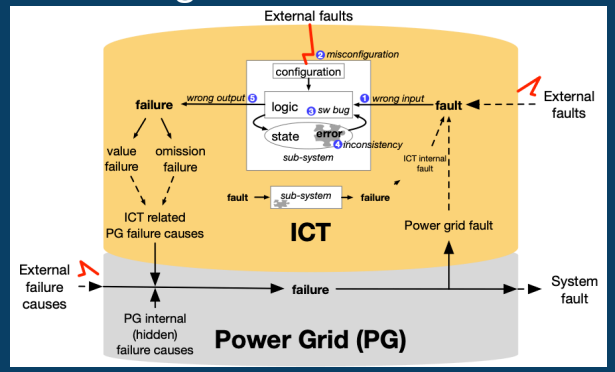
CINELDI result: Stochastic Petrinet model for dependability assessment and integrated power grid and ICT support (WP2)

Challenge and objective:

- Importance and consequences of inconsistencies between physical and cyber system states



- The ICT and power system experts use different failure taxonomy, from IFIP and IEC, respectively, that inhibits good collaboration



Work performed:

- Metric for inconsistencies defined
- Consequences of inconsistencies assessed by use of the modelling approach Stochastic Activity Networks
- A sensitivity analysis has been performed to identify the most critical parameters affecting this inconsistency
- Comparison of failure taxonomy from IEC and IFIP, and proposed alignment

Significant results:

- The study has shown the direct and high impact of value failures, i.e. sensor or controller data which are valid but wrong.

Impact for distribution system innovation:

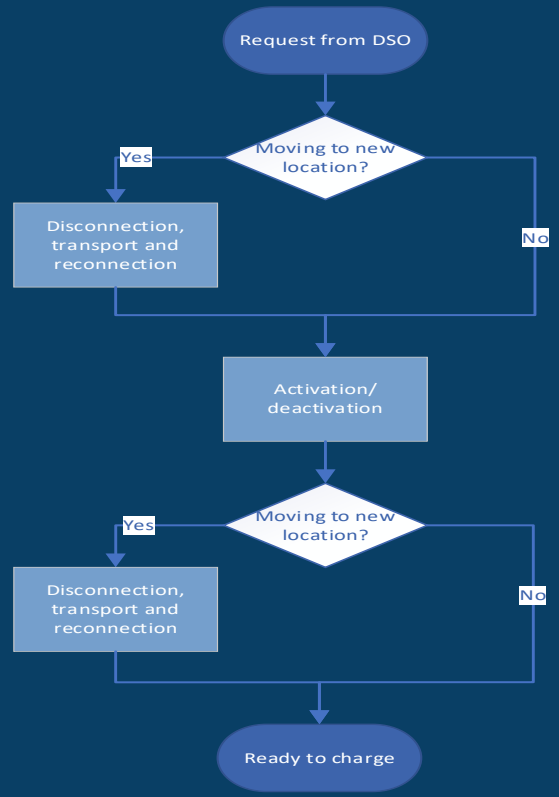
- Common taxonomy of ICT and power system experts is a prerequisite for improvement of analysis of the cyber physical power system.

Reference in CINELDI:

- R. Muka, F.B. Haugli, H. Vefsnmo and P.E. Heegaard: "Information Inconsistencies in Smart Distribution Grids under Different Failure Causes modelled by Stochastic Activity Networks", AEIT International Annual Conference 2019

CINELDI result: Use case: New concept of using mobile battery in distribution grids (WP2)

Challenge and objective:
The load and generation in future distribution grids are expected to vary more and be more unpredictable. With today's planning criteria the grid planning is based on a worst case, and can result in over investment. Provision of localized flexibility services to distribution grid operators on short notice, could lower grid investment costs.



Work performed:
- Based on communication with DSOs the work flow of mobile battery operation is described in detail in a use case

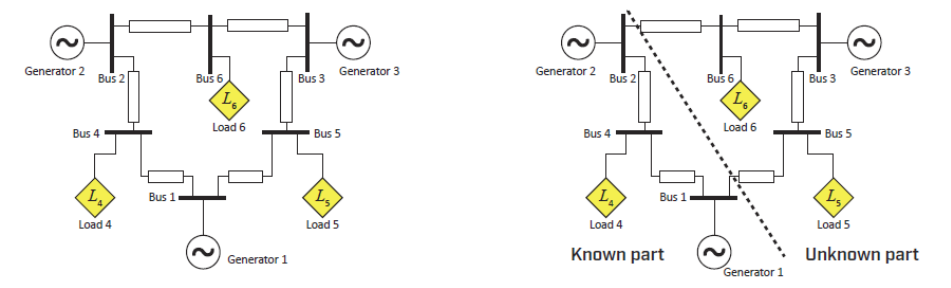
Significant results:
- The idea is described in a Use Case

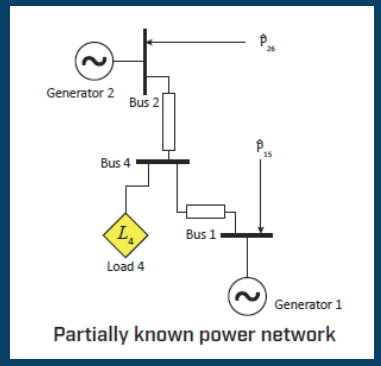
Impact for distribution system innovation:
- Readily available and affordable mobile flexible resources would allow the DSOs to operate closer to grid limitations and postpone investments.

Reference in CINELDI:
- A. Morch et.al.: "Use cases for future (2030-2040) smart distribution grid operation", CINELDI report 02:2019

CINELDI result: Observability in TSO/DSO interface (WP3)

Challenge and objective:
The introduction of distributed energy resources introduces a lot of uncertainties, and fast dynamics. The consumers' privacy consideration, lack of measurement units and geographical difficulties call for new methods for distributed monitoring of power grids.





Work performed:
- Introduced the concept of partially known power grids.
- Developed procedures for simultaneous input and state estimation.
- Use covariance intersection for data fusion between different sensors.
- Introduced fully distributed state estimation for distribution networks.

Significant results:
- The fast dynamic states and transients of a power network are captured using dynamic procedures.
- The number of measurements needed for state estimation was reduced significantly.
- All available measurements with different measuring rate including PMUs, SCADA and smart meters are used at the same time.

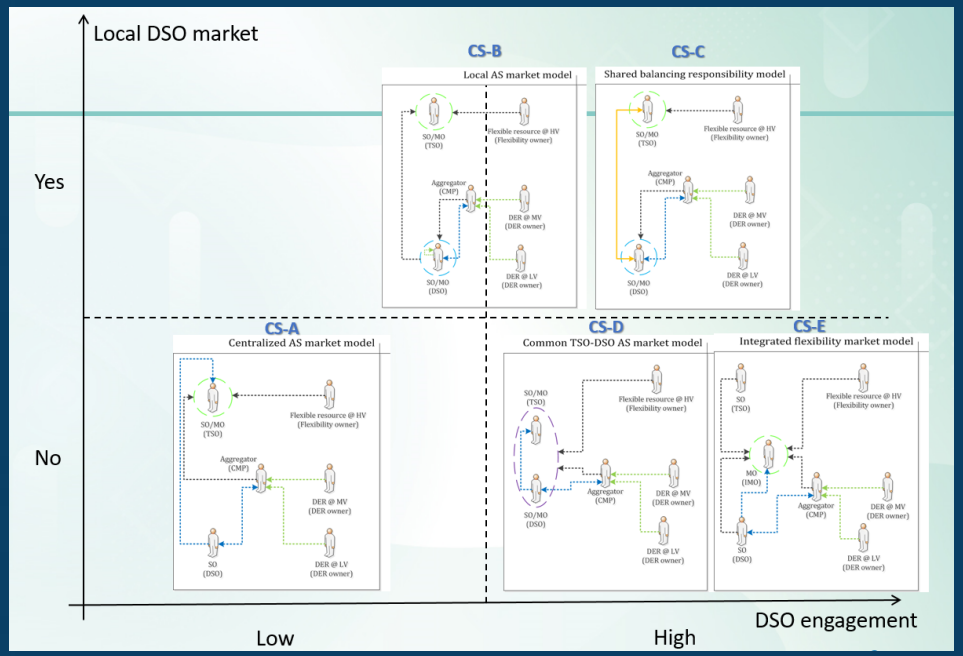
Impact for distribution system innovation:
1. Can be developed to be used for autonomous self-healing controller systems.
2. Can be exploited to do sensor placement optimally.
3. Fault detection scheme can be derived based on the proposed algorithm.

Reference in CINELDI:
- M. Abooshahab, M. Hovd and R. Bitmead: "Disturbance and state estimation in partially known power networks", IEEE Conference on Control Technology and Applications 2019 (SINTEF Blog)
- R. Bitmead, M. Hovd and M. Abooshahab: "A Kalman-filtering derivation of simultaneous input and state estimation", Automatica 2019

CINELDI

CINELDI result: Coordination schemes and market architecture (WP3)

Challenge and objective:
The growing need for ancillary services requires implementation of coordinated market schemes allowing procurement of flexible resources from the distribution grid for ancillary services in both distribution and transmission networks.



Work performed:
- In cooperation with H2020-project SmartNet (2016-2019) a set of alternatives for the future TSO-DSO coordination schemes has been developed and comparatively evaluated

Significant results:
- Five coordination schemes for TSO-DSO interaction, necessary for procurement and activation of ancillary services. Relevant for the operation of transmission and distribution grids, market architectures and input to regulations.

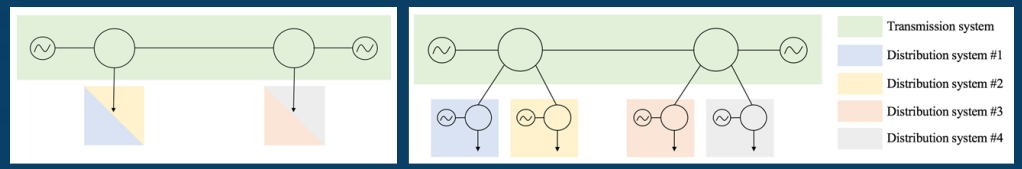
Impact for distribution system innovation:
- Creates a starting point for development of technologies, defines the required TSO-DSO data exchanges, outlines new business models for aggregation and trading of flexibilities.

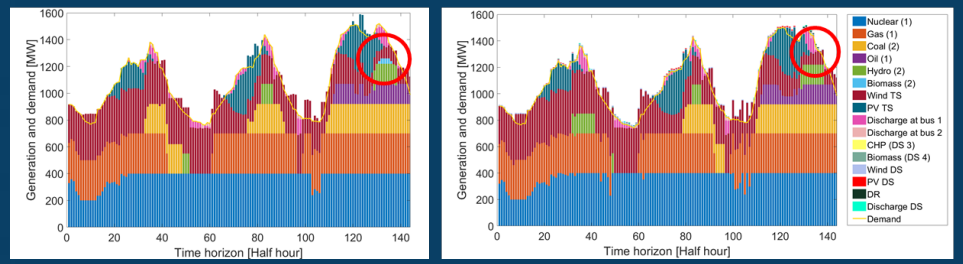
Reference in CINELDI:
- A.Z. Morch, H. Sæle, D. Siface, G. Migliavacca, H. Gerard and I. Kockar: "Market architecture for TSO-DSO interaction in the context of European regulation", EEM2019 Conference

CINELDI result: Modelling TSO-DSO coordination: The value of distributed flexible resources to the power system (WP3)

Challenge and objective:

- TSO-DSO interaction is mainly based on a uni-directional flow of information (from TSO to DSO)
- The resources in the distribution systems are not utilized fully in overall power system operations.
- Limited information in existing literature how the coordination of the TSO-DSO can and should be optimized.
- Limited insights to the potential value coordination may bring to the overall power system operations.





Work performed:

- Optimization of the power system operation through modelling TSO-DSO coordination, where flexibility is provided by distributed energy resources located in the distribution systems.
- The optimization problem is modelled as deterministic mixed integer linear programs with unit commitment and economic dispatch.
- Case studies: 1) Top-down, 2) Coordinated TSO-DSO problem.

Significant results:

- The total costs of power system operations are reduced when distributed flexible resources are incorporated under a joint coordination framework

Impact for distribution system innovation:

- Reduced costs when including flexible resources in the operation of the power system (case result)

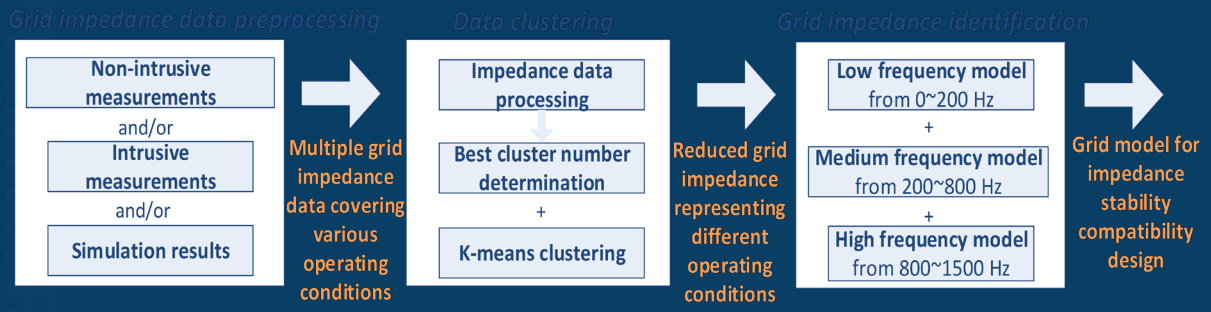
Reference in CINELDI:

- H.H. Grøttum, S.F. Bjerland, P. Crespo del Granado and R. Egging: "Modeling TSO-DSO coordination: The value of distributed flexible resources to the power system", EEM2019 Conference
- Master's thesis in Industrial Economics and Technology Management (June 2019)

CINELDI result: A Data-driven Approach to Grid Impedance Identification for Impedance-based Stability (WP4)

Challenge and objective:

- Instability caused by inappropriate damping design of grid-connected converters under specific grid impedance makes the grid impedance estimation a crucial issue.



Work performed:

- To guide the design of system controllers to reach a more stable and adaptive system. To deal with various operating conditions, a three-stage data-driven approach for grid impedance identification with three different frequency ranges is proposed. The motivation is to take advantage of massive data coming from measurement and/or simulation.

Significant results:

- Clustering is used to partition the processed impedance data
- A high order grid impedance model is generated for each frequency range, in accordance with the practice of resonance mitigation design

Impact for distribution system innovation:

- A more stable and flexible system is achieved by an improved controller design and tuning.

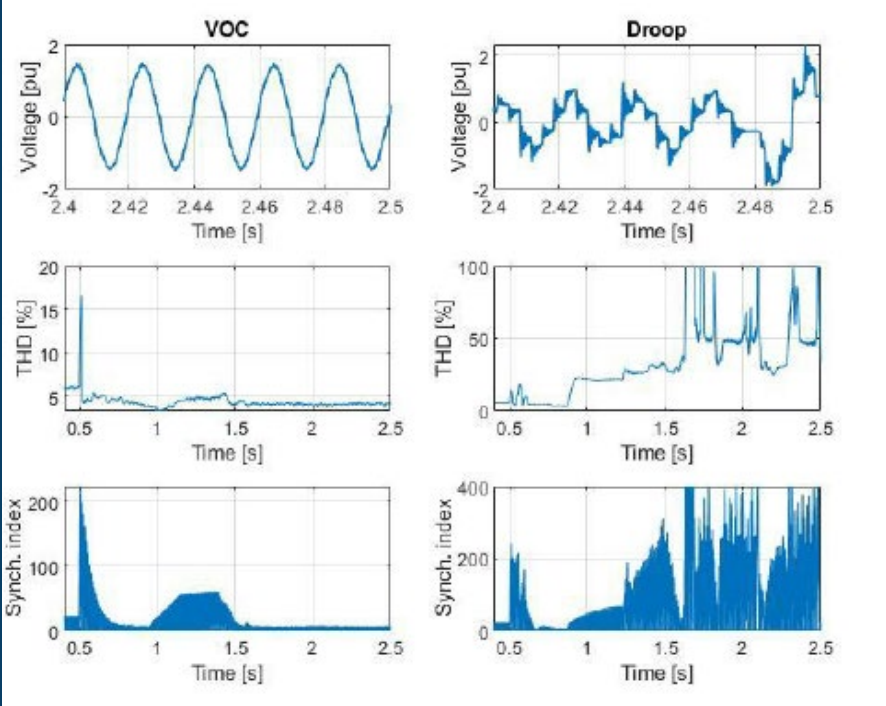
Reference in CINELDI:

- C. Li, M. Molinas, O.B. Fosso, N. Qin and L. Zhu: "A Data-driven Approach to Grid Impedance Identification for Impedance-based Stability", IEEE Power Tech, 2019

CINELDI result: Impact of Virtual Oscillator Control on the instantaneous properties of VSC output voltage in distorted island grids (WP4)

Challenge and objective:

- Synchronization in island electrical grids dominated by power electronics is challenged by the absence of a grid reference to follow, lack of inertial sources and the usual lack of communication among the units.



Work performed:

- This paper investigates the instantaneous properties of voltage and frequency of Voltage Source Converters (VSCs) when they are controlled by Virtual Oscillator Controllers (VOC) in a distorted island grid.

Significant results:

- The results provide convincing evidence for the adoption of a more complex controller as the VOC in island grids that will naturally be more vulnerable to voltage distortions.
- The results encourage further explorations into other potential benefits of VOC in island grids
- The new approach to synchronize in cases where the classical droop control fails

Impact for distribution system innovation:

- Topologies currently challenging seem to be possible to solve with the new technique.

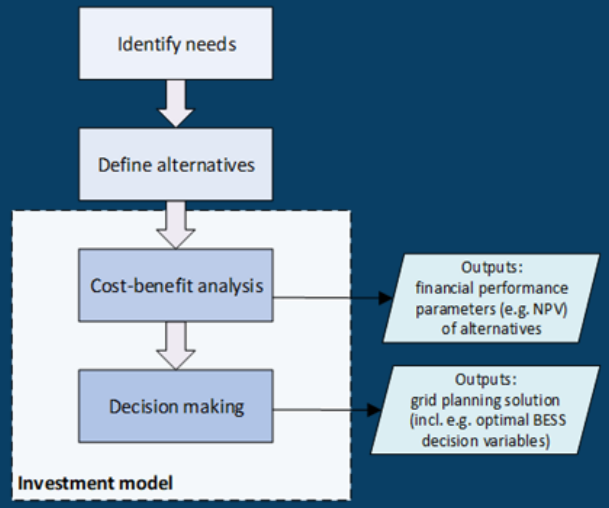
Reference in CINELDI:

- M. Melby, M. Molinas and O.B. Fosso: "Impact of Virtual Oscillator Control on the instantaneous properties of VSC output voltage in distorted island grids", IEEE 45th Annual Conference of the IEEE Industrial Electronics Society, 2019

CINELDI result: Methods for Cost-Benefit Analysis (CBA) of Battery Energy Storage in Power Grids (WP5)

Challenge and objective:

- Batteries can be deployed at strategic locations in the grid and perform active and reactive power control for better grid utilization, as an alternative to reinforcements.
- The lack of established computational methods for including batteries in grid planning is a barrier for taking research-based models into practice.



Work performed:

- Systematic overview of relevant methods reported in the literature.
- Contrasting the state of the art for these research-based methods with real-world applications.

Significant results:

- CBA methods should handle investment timing as well as sizing and siting of the batteries.
- CBA of batteries basically weights investment costs against operational benefits. The methods therefore need realistic modelling of the operational aspects of batteries: Multi-period AC, load and generation uncertainties, degradation.

Impact for distribution system innovation:

- Good CBA methods are crucial for analysing batteries and other flexible resources as alternative to traditional grid upgrade solutions.

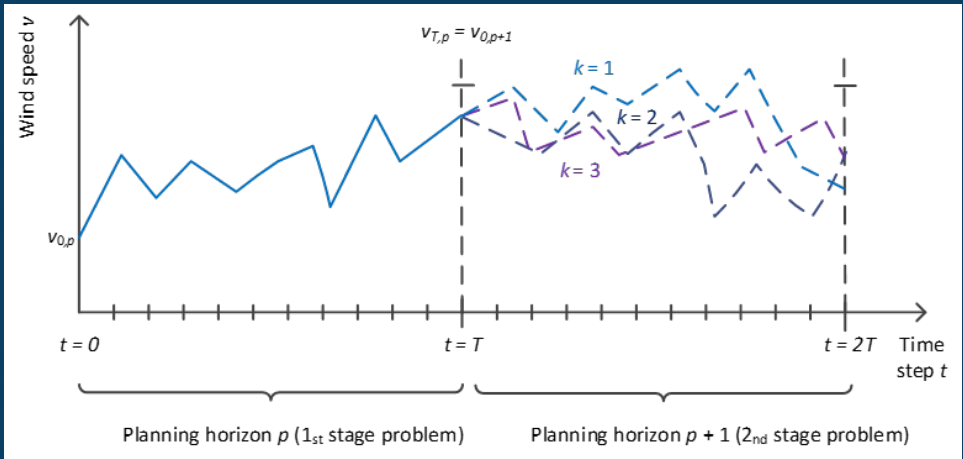
Reference in CINELDI:

- I.B. Sperstad, M. Korpås et.al.: "Methods for cost benefit analysis of batteries in distribution grids", EERA JP Smart Grids - SP Energy Storage, Working paper, 2020

CINELDI result: Incorporating energy storage and variable renewables in power flow analysis (WP5)

Challenge and objective:

- The hypothesis is that the optimal operation of a distribution system with energy storage can be investigated/determined using multi-period optimal power flow (MPOPF) techniques.
- The objective is to value stored energy for future use, taking into account wind and PV uncertainties.



Work performed:

- Develop a method for storage valuation inspired by optimization principles from hydropower scheduling
- Including the energy storage model in MPOPF, together with stochastic wind and PV
- Performing analysis on a Norwegian test case.

Significant results:

- The storage model proved to be an effective and robust method for treating wind and PV uncertainties.
- Should be further developed to handle load uncertainties and use of energy storage for reliability purposes.

Impact for distribution system innovation:

- The methods and models presented here can be part of the basis for the next generation of power flow tools used in practice.

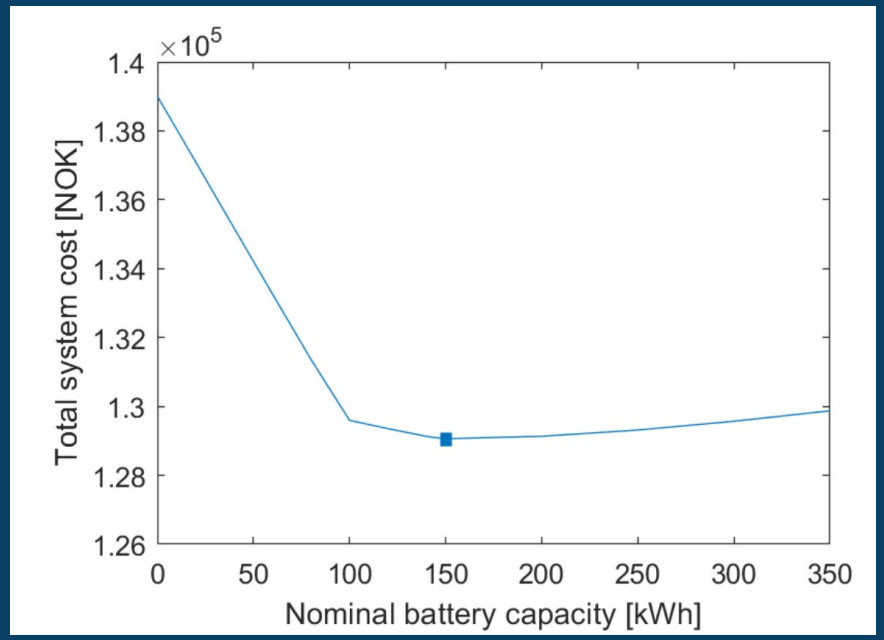
Reference in CINELDI:

- I.B. Sperstad and M. Korpås: "Energy storage scheduling in distribution systems considering wind and photovoltaic generation uncertainties", Energies 12(7), 2019

CINELDI result: Optimal Operation of Battery Storage for a Subscribed Capacity-Based Power Tariff Prosumer (WP5)

Challenge and objective:

- The cost of peak power for end-users subject to a demand charge may be substantial
- The objective is to analyse if battery storage can reduce consumer costs while ensuring the longevity of the battery.



Work performed:

- Build optimization model for local PV-battery-load system with grid connection
- Including battery degradation into the model
- Perform Norwegian case study based on a swimming facility

Significant results:

- Battery storage can be beneficial for peak-shaving of swimming facility loads even with todays investment costs
- Degradation modelling is important to get realistic estimate of economic potential, as degradation may reduce the lifetime by ~1 year.

Impact for distribution system innovation:

- Detailed simulation models gives better decision aid for end-users to identify profitable battery investments.
- Practical battery models with degradation, also usable for other applications in the grid

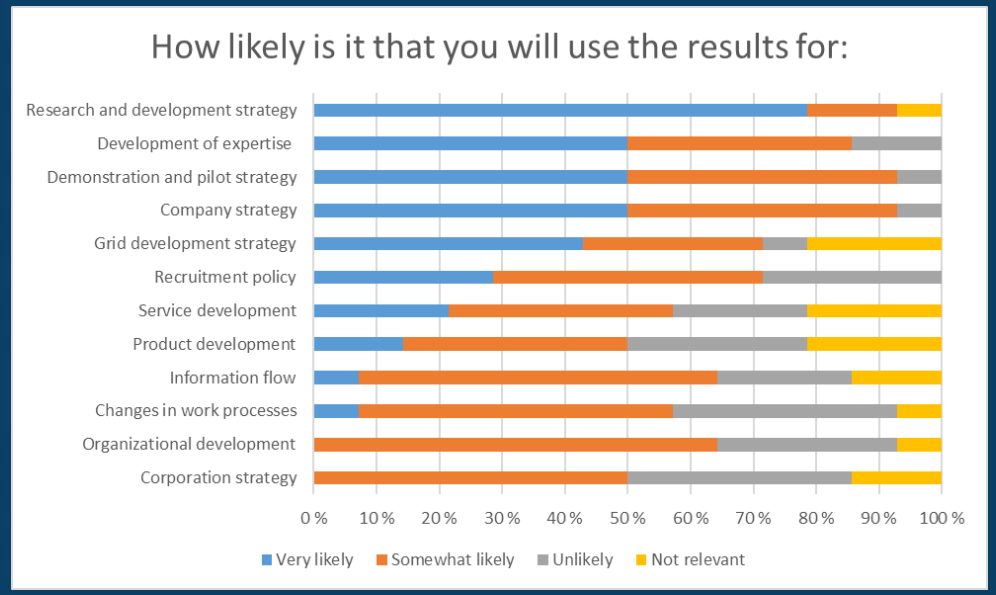
Reference in CINELDI:

- F. Berglund, S. Zaferanlouei, M. Korpås and K. Uhlen: "Optimal Operation of Battery Storage for a Subscribed Capacity-Based Power Tariff Prosumer", Energies 12(23), Nov. 2019

CINELDI result: Use of results on driving forces and scenarios by the CINELDI partners (in the industry) (WP6)

Challenge and objective:

- Grid companies, technology providers, market operators etc. need a robust strategy for the cost-efficient transition to the future flexible, intelligent and robust grid. Driving forces and scenarios for the future grid is a a useful foundation for this strategy.



Work performed:

- A survey was conducted among CINELDI-partners to gain insight into how the results on driving forces and scenarios have been used already and how the partners plan to use the results in the future

Significant results:

- >= 50 % of the respondents will use the results for:
- developing research and development strategy, for which expertise they will focus on in the human resource development,
- developing demonstration and pilot cases, and
- developing the overall company strategy.

Impact for distribution system innovation:

- Building new knowledge and gaining insight into possible future scenarios, as a basis for increased understanding and to prepare for the future.

Reference in CINELDI:

- T.S. Hermansen, G. Kjølle, H. Vefsnmo, K. Sand: "Driving forces for intelligent electricity distribution system innovation", CINELDI report 01:2020