RESERVE

HOW RESERVE SOLUTIONS ENSURE GRID STABILITY WITH 100 % RENEWABLE ENERGY!

RESERVE TACKLES POWER GRIDS WITH UP TO 100 % RES GENERATION

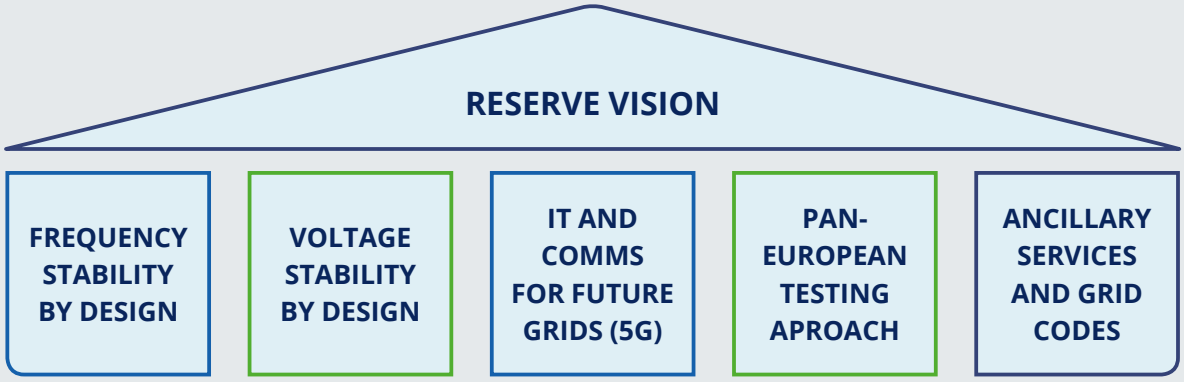
The EU has set an ambitious goal of using at least 32% Renewable Energy Sources (RES) in Europe by 2030. As a result, many new RES, driven by power electronics, will be installed in the grid. This change affects the fundamentals of grid operation and makes rethink the basics of grid control and automation necessary. This is the challenge which RESERVE addresses.

RESERVE has analysed what introducing 100% RES means for the distribution and transmission grids. RESERVE moves from the components to the system level, defining completely new operational methods that could be the key to solving the problem of controlling grid frequency and voltage in the future. These solutions are urgently needed given that high penetration of renewables for short time periods is a reality even today, so new solutions for grid automation and control are already required.

RESERVE focuses on these changes and on how to manage the power electronics-driven RES components addressing the following questions:

- How are we going to maintain frequency stability in future power systems?
- How can power electronics play a new role and actually make the grid even better than before?
- What is a good systems level approach for future power systems?
- Which role will communication infrastructures play?
- How should we change the grid operational logic to adapt to the new grid paradigms?

The RESERVE project is developing answers to these questions. Its vision is based on the following pillars which represent the areas of activity of the project:



The RESERVE Vision

The project results are reported in the RESERVE deliverables. RESERVE's scientific results have been published in 3 books and in over 30 scientific conferences, with 14 articles having been published in international peer-reviewed journals. The complete list of publications and all of the project deliverables are available on the project web site (*https://www.re-serve.eu/library.html*).

RESERVE GRID STABILITY SOLUTIONS FOR UP TO 100 % RES

The challenges of having high RES penetration include ensuring grid stability with much less rotational inertia being provided by large synchronous generators, identifying and implementing needed updates to harmonise network codes and the provision of a communication infrastructure supporting near-real-time services with high reliability. RESERVE has developed innovative frequency and voltage control approaches to ensure system stability, supporting them with validation in large scale simulations and field trials and by promoting the research concepts and policies as harmonised network codes.

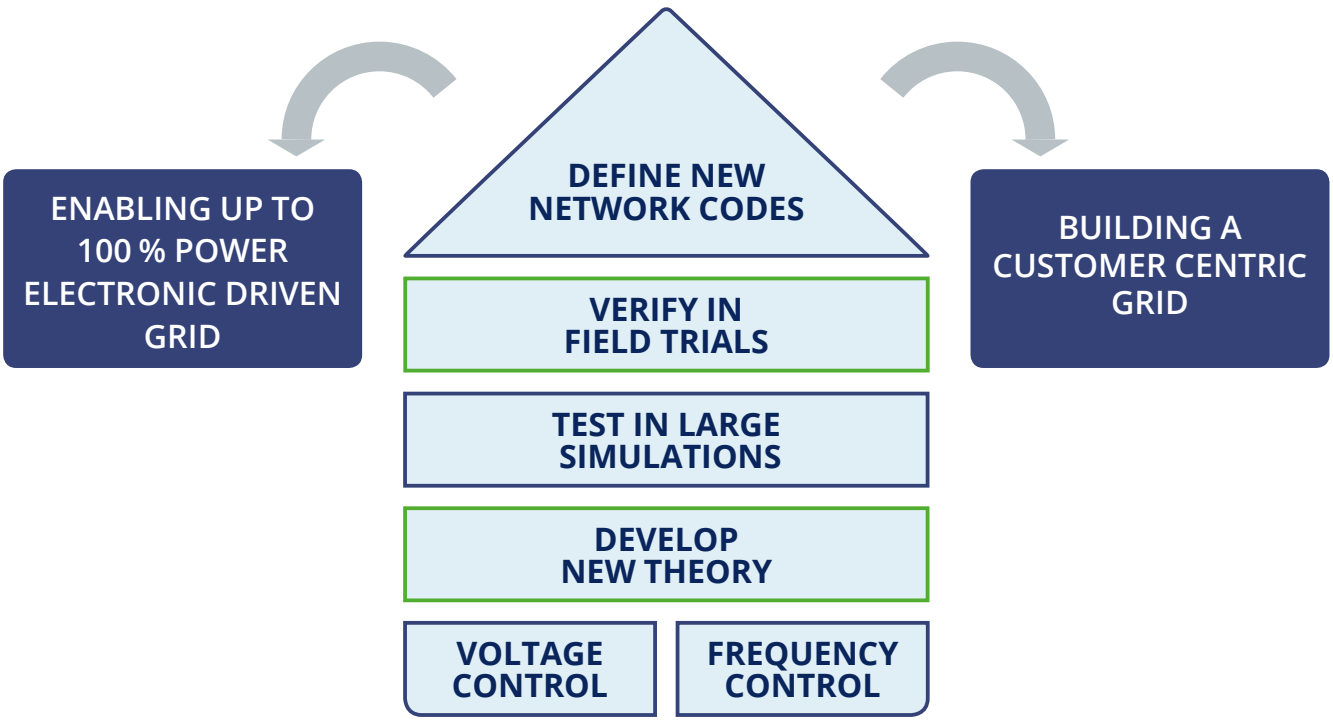
RESERVE investigates using 5G-enabled ICT to provide the communications services needed to ensure system stability by enabling near real-time control of the distributed energy network. Performance characteristics of the new control mechanisms have been investigated through the integration of grid simulations and live 5G wireless communications as hardware in the loop. A pan-European multi-site simulation test-bed, which brings together the best facilities in Europe, was created in order to enable a large-scale validation of the new concepts.

RESERVE captured the main technical characteristics of the solutions by defining four exemplary scenarios. They form the basis for the development of automation, control and ICT technologies performed in the project.

In power systems with low inertia, improvements to frequency control are needed to use Energy Storage Systems (ESSs) and volatile solar and wind power to slow down the change in frequency caused by disturbances, maintain it within the allowed range and restore it to its nominal value. Frequency control scenarios with 100% RES have been developed at the high and medium voltage grid levels, one of which using hydro-electric power to provide inertia. The scenario without hydro-electric power uses the concept of Linear Swing Dynamics (LSD) to provide faster control and considers DC grids.

One voltage control scenario uses a novel Virtual Output Impedance (VOI) control technique to address the dynamic instability in distribution systems coming from the proliferation of power-electronic-based RES, ESSs and loads. A second voltage control scenario manages the voltage and energy flows using power converters instead of today's use of on-line tap changing transformers and shunt devices that inject or draw reactive power.

The RESERVE strategy



FREQUENCY STABILITY BY DESIGN

Description & Benefits

Reducing the number of large centralised generators as more distributed generation is introduced at medium and low voltage levels means that the amount of rotating mass drops severely, resulting in a reduced ability to provide inertial response to maintain grid stability. RESERVE has developed novel definitions of "frequency" under dynamic conditions and of "Rate of Change of Frequency" (RoCoF) in the Frequency Divider Formula (FDF) and Linear Swing Dynamics (LSD), for which recommendations for new Ancillary Services and Network Code definitions have been drafted.

Frequency Divider Formula (FDF) approach:

- What it is? FDF is a mathematical tool that estimates the frequency variations at every bus of the network after a contingency.
- How it works: the estimation is based on a linear relationship between bus frequencies and synchronous machine rotor speeds based on the augmented admittance matrix of the system.
- What it is for? the applications of the FDF and its variations include monitoring, dynamic state estimation, frequency control, advanced models of power system devices, identification of critical parts of the system that need to be measured, etc.
- Benefits: FDF gives an accurate and complete picture of the behavior of the frequency in systems with low-inertia.

Linear Swing Dynamics (LSD) approach:

- What it is? LSD emulates conventional synchronous generators by providing virtual inertia and participating in frequency control while achieving enhanced dynamic behaviour and linearised characteristics.
- How it works: The LSD concept linearises the non-linear power-angle characteristic by tailoring voltage control, exploiting the permitted voltage tolerance in power systems.
- What it is for? RES-tied power converters, namely Virtual Synchronous Generators, emulate the classical synchronous generator.
- Benefits: LSD exploits the degrees of freedom introduced by power electronics. It incorporates the advantages of the synchronous generator while overcoming its drawbacks (i.e. non-linearities) by achieving a linear dynamic behaviour offering highly-predictable dynamics, enhanced system stability and simplified stability analysis of future power systems.



VOLTAGE STABILITY BY DESIGN

Description

High penetration of RES can cause short time-frame dynamic instabilities and large time-frame steady state voltage unbalances and over or under voltage. These key issues are-addressed by the concepts of Dynamic Voltage Stability Monitoring (DVSM) and Active Voltage Mangemant (AVM).

Using DVSM, the local grid impedances are calculated at the distributed generators. To do this, small signal perturbations are injected locally and used to measure the grid impedance. The measured grid impedance is used to synthesise a virtual inverter output impedance which stabilises the inverter.

AVM works by extracting the local load profile, which is used to determine the inverter set-points to ensure that the power losses and voltage unbalances are minimised.

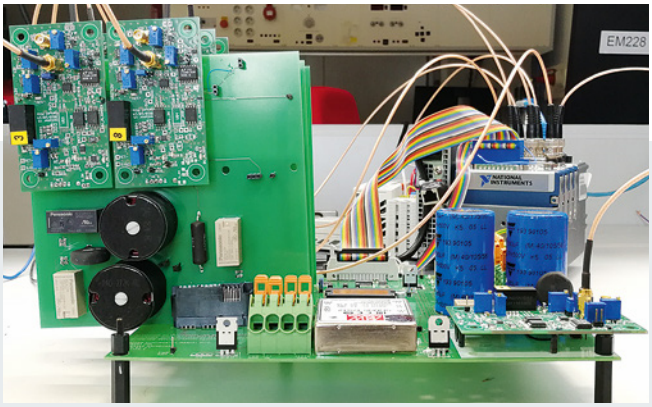
Benefits

The proposed techniques contribute to grid stability, enabling a smooth transition from conventional distribution grids to future power electronics driven grids.

RESERVE PROGRAMMABLE INVERTER

Description

The programmable inverter prototype, developed by the RESERVE project, accurately measures the grid impedance from the point of interconnection with the grid. Its low-cost gives it a significant advantage over currently available inverters on the market. It is used in the RESERVE voltage control field trials on the ESBN network in Ireland and in laboratory tests in the RWTH laboratory in Germany. Discussions regarding the commercialisation of the inverter are ongoing.



The RESERVE Low Power Inverter Prototype

Benefits

Grid operators can use this device to measure grid impedances at nodes in the grid, enabling grid stability to be monitored in real-time. It can be included in existing residential photo-voltaic inverters as a software component. It can also be used to enable ancillary services, such as impedance measurement and local harmonic stability monitoring, to be offered to the grid operator.

5G-BASED ICT REQUIREMENTS DEFINITION AND 5G EXPERIMENTATION TO SUPPORT COMMERCIALISING THE RESERVE CONCEPTS

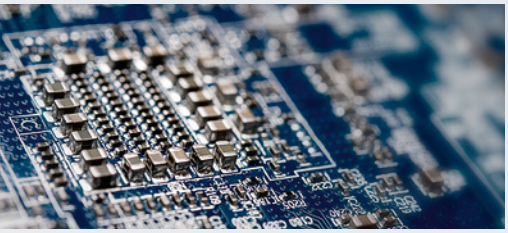
Description

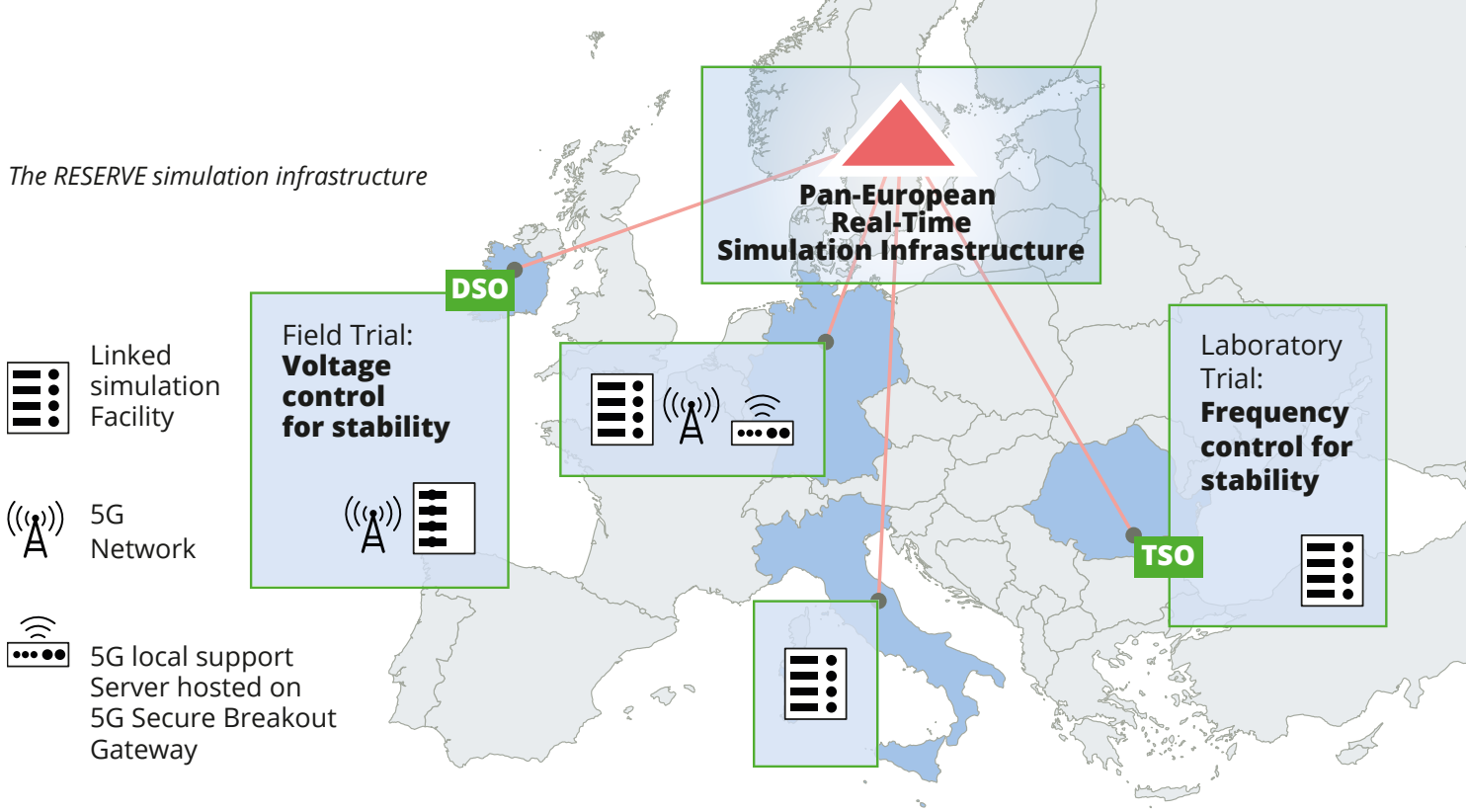
In RESERVE, we have investigated the communication requirements of the new frequency and voltage techniques which require communications to the many endpoints in the new distributed power grid architecture. Wireless cellular networks, such as 5G, offer simple, flexible, cost-effective deployment solutions complementing fixed communication infrastructures in the context of the commercial scale use of the new techniques developed by RESERVE.

We have tested (as laboratory tests of 4G and 5G live mobile networks connected to power network simulators) the performance of several communication protocols (AMQP, MQTT, IEC 61850) which could be used to implement the new techniques, resulting in recommendations for optimal 5G solutions.

Benefits

Our results show energy providers how 4G and 5G networks will form an important component of future smart grid communications by supporting the deployment of the new techniques developed in RESERVE.





PAN-EUROPEAN CO-SIMULATION INFRASTRUCTURE (VILLAS ENVIRONMENT)

Description

The RESERVE simulation infrastructure was developed to interconnect many individual European simulation facilities to simulate and test the RESERVE frequency management concepts in large scale simulations.

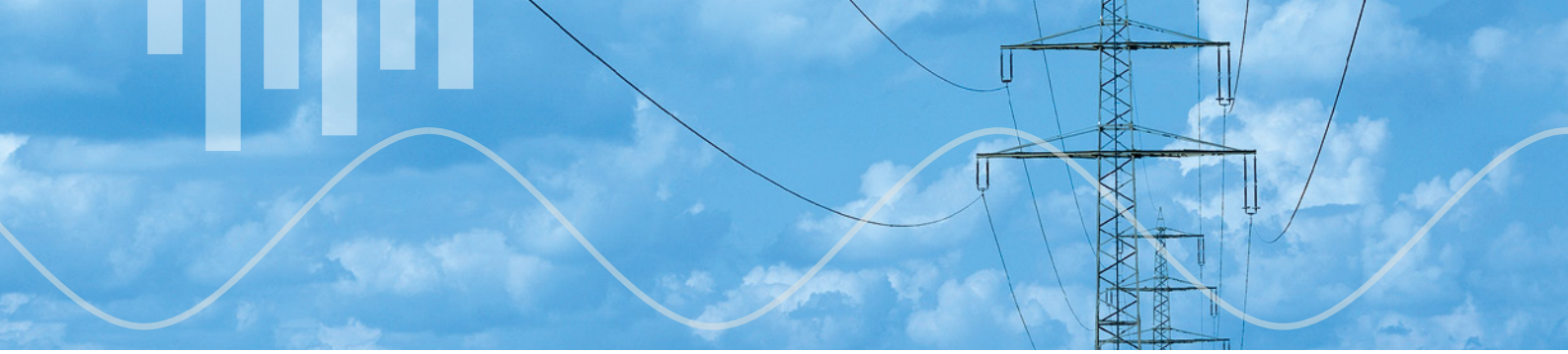
The RESERVE co-simulation infrastructure includes distributed computing capacity, real-time power system simulators, distribution system field devices and a distributed cloud system, located in the RWTH laboratory, which includes edge computing capabilities as well as a mobile base station connected remotely to a mobile core network (located at an Ericsson facility near Aachen) and to the simulators in the RWTH laboratory.

The goal of this infrastructure is to support simultaneous large-scale power system real-time simulation and Hardware-In-the-Loop (HIL) tests using simulators and hardware which are not in the same geographical location. Two new software applications were developed to tremendously increase simulation capacity using distributed real-time simulations: VILLASnode and DPsim. VILLAS stands for "Virtually Integrated Laboratory for Large System Simulation". VILLASnode enables the low latency exchange of simulation variables between different locations. DPsim is a dynamic phasor based simulator that is designed to cope with the latencies inevitable in distributed simulation scenarios.

Since the power system is simulated in real-time, the wireless connection between the base station and the simulators allows us to test new monitoring and control concepts in a setting much closer to reality than in an offline simulation. Consequently, voltage and frequency control algorithms developed in the RESERVE project could be deployed to the distributed cloud system or the individual generation units in the simulation to test their robustness in realistic operating conditions regarding the available time to update control values and the reliability of the communication link.

Benefits

The VILLAS co-simulation environment enables RESERVE to simulate and test a range of power network scenarios for the use of the RESERVE frequency management techniques. A single conventional simulation environment would not have had the capacity to run such resource intensive simulations.



RESERVE VOLTAGE CONTROL FIELD TRIALS IN IRELAND

Description

The novel voltage control methods developed within the project are being extensively tested in field trials in the power grid of ESB Networks, the Irish DSO. Five inverter-based Distributed Energy Resource technologies supplemented by leading-edge power monitoring devices have been deployed across a total of 7 trial sites.

The technologies deployed in the Irish voltage control field trials are the Active Voltage Management (AVM) and the Dynamic Voltage Stability Monitoring (DVSM) Control Techniques:

Active Voltage Management (AVM) Control Technique Field Trials

This set of trials leverage 4 existing inverter-based technologies in a novel way to control voltage. The field trial deployments use a mixture of both mature and cutting edge technologies.

- Vehicle to Grid (V2G) Charger Field Trial – incorporating the first V2G system deployed in Ireland, this trial is operating in the Dublin city area.
- Battery Systems Field Trials – located at 3 locations in Cork & Tipperary, these trials examine the impact of the AVM Control Technique in both urban and rural contexts.
- Smart Solar PV Inverter Trial – located at the ESBN National Training Centre in Portlaoise this trial combines a ground mounted Solar PV Array with advanced programmable Smart Inverters.
- Controllable Air Source Heat Pump System – this trial examines the controllability of electrified heating at a school outside of Nenagh, Co. Tipperary.

Dynamic Voltage Stability Monitoring (DVSM) Control Technique Field Trial

- The ESB National Training Centre (NTC) in Portlaoise provides a real, yet segregated, network for testing this concept using the prototype programmable inverter developed in the project. Upgrades at the Burnwood 38 kV Gas-insulated Switchgear (GIS) Station in the NTC have been made to facilitate this trial.

Benefits

The results of the field trials have validated the concepts and provide a promising context for the commercialisation of the concepts for voltage control and for the inverter developed by RESERVE.

The V2G Charger Field Trial located in Dublin, Ireland

RESERVE FREQUENCY CONTROL LABORATORY TRIAL IN ROMANIA

Description

For the trial, a set of Phasor Measurement Units (PMU) was installed in the power grid of Transelectrica, the Romanian TSO, providing datasets for use in RESERVE simulations which were recorded during severe perturbations with significant impact on the system frequency. These datasets are used as input scenarios for real-time and off-line simulations to test and validate frequency control strategies on various time scales and to propose new and modified network codes and ancillary services.

Benefits

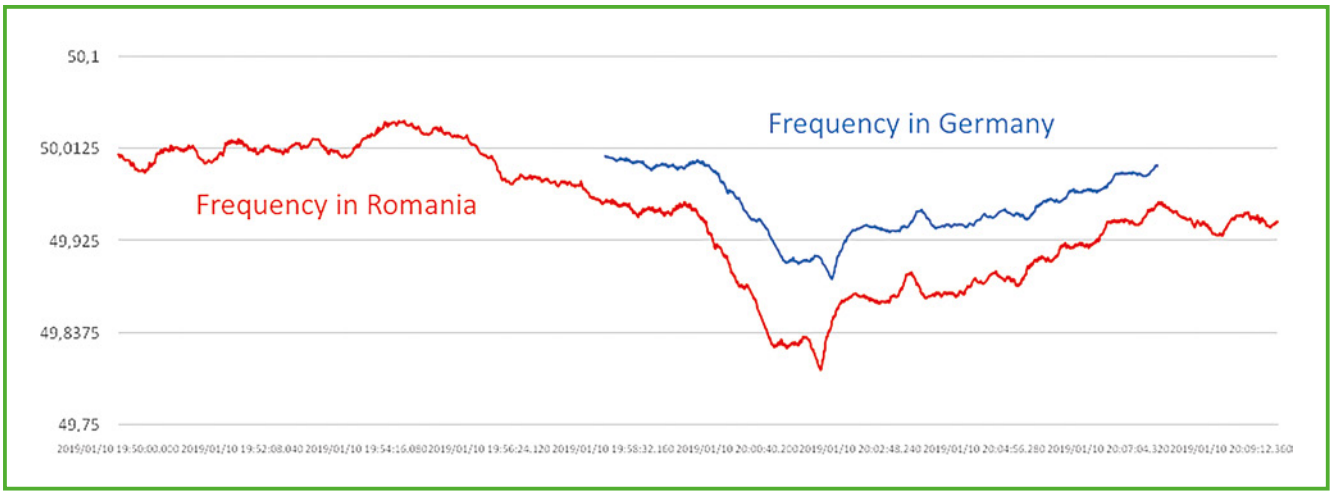
Monitoring system frequency, using the frequent measurements provided by PMUs, helps RESERVE to understand the dynamic behaviour of the interconnected power system of Continental Europe. One of the most important questions facing the RESERVE project is to determine whether the frequency differs significantly at remote points in the ENTSO-E power system. This issue was analysed in both very short time-frames (1-2 seconds, specific to short-circuits, but with limited geographical impact) and in a quasi-steady-state time-frame (>5 seconds, specific to power unbalance, when the same effects could be experienced by the entire interconnected power system).

An important event, illustrated in the graphic below, was measured as part of the RESERVE project trials, which occurred on January 10th, 2019, starting at 19:55 hours, and lasting for at least 15 minutes.

During the event, the frequency gradually dropped and after 7 minutes it went below the threshold value of 49.8 Hz, causing load-shedding to be applied, which allowed recovery towards the nominal 50 Hz frequency. The event is under analysis by ENTSO-E and the main cause of the event is unknown at this date.

The frequency was almost identical in both Germany and Romania showing that, under the current operating conditions of the Continental European power system, with ample mechanical inertia available across the system, the generators maintain synchronism with each other. This experience encourages us to support proposals for better monitoring of power flows across Europe.

Placement of PMUs in the Romanian Power System.



Frequency variation in Romania and Germany during the continental event on January 10th, 2019.

IMPLEMENTING THE RESERVE REGULATORY STRATEGY

As well as defining technical solutions for how the future grid can be operated and controlled with up to 100% RES, RESERVE has identified other impacts needed to support the change:

- The ancillary services (the services which maintain grid stability and security) which must be adapted as we change from large centralised generation towards large-scale distributed RES, and
- The network codes (the rules by which the grid is operated), which must be adapted to enable running the power grid with up to 100% RES,
- The existing business models of the grid operators and other stakeholders, which need to be adapted.

Ancillary Services

The physical phenomena in power systems become faster and more complex as RES penetration increases, requiring a new structure for ancillary services. Additionally, the significant increase in distributed generation opens up the possibility that customers can become service providers.

RESERVE proposes adaptation of some existing ancillary services (such as a new approach for "Frequency Containment Reserve" and for "Voltage control"), and the definition of new ancillary services to provide:

- Synthetic inertia
- A zonal frequency reference
- Power system flexibility
- Specifications and requirements for linear behavior in swing dynamics
- Congestion mitigation
- Reactive power reserves

Benefits

RESERVE proposals enable the use of the full potential of distributed generation to improve the stability and safety of the power systems, as well as enabling the decentralisation of frequency and voltage regulation.

Network Codes

Currently, 8 European network codes (NCs) are in force, which are grouped into three families (connection, operations and market) and reflect the actual grid requirements to cater for a 20% level of RES penetration. The European Commission has set a new target of 32% RES integration in power grids by 2030. Considering this new target, as well as its overhead estimates, existing NCs will need to be updated, and the possibility of creating new NCs has also been considered in RESERVE.

New Network Code for storage

Higher RES penetration leads to an increase in the importance of storage to ensure the stability of the power systems. Storage is quickly becoming the fourth pillar of the power systems augmenting the "classical" pillars of generation, consumption and the power network. Therefore a dedicated network code for storage is proposed by RESERVE. This will lead to a new definition of the business model for storage facilities, as the existing ones (based on consumption and pumping when the electricity is cheap and generation when the electricity price is high) will be inadequate in the new scenario.

Benefits

When there are high levels of RES in use, storage is needed to support the power systems operation by providing ancillary services. The proposed new network code for storage will facilitate the adoption of the new operational techniques by power grid operators.

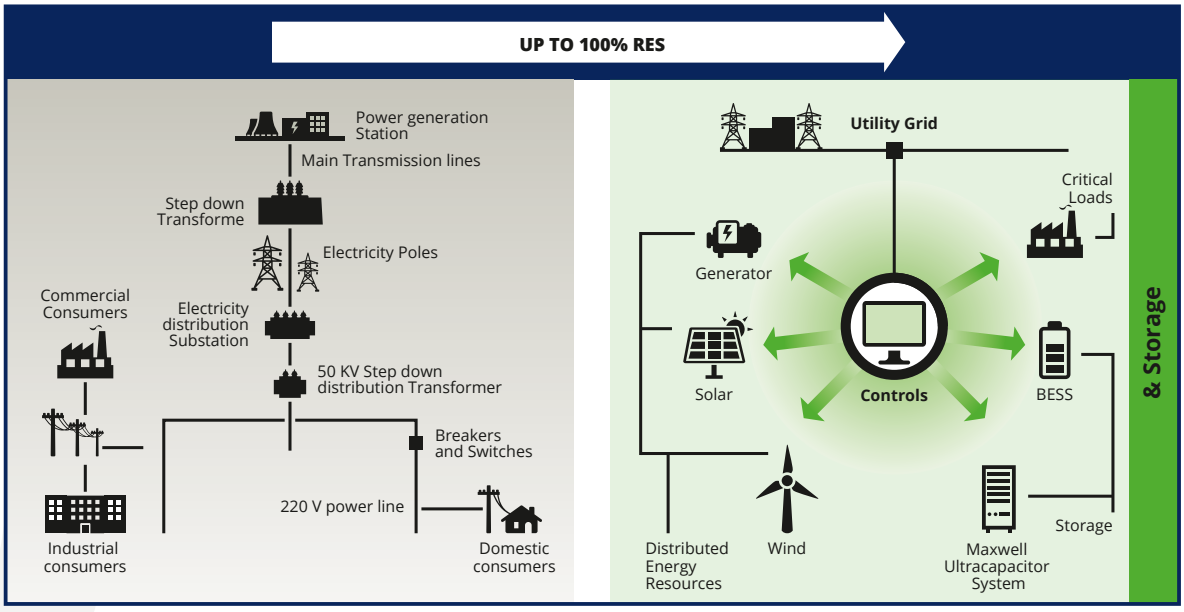
Updates to existing Network Codes

In order to introduce the techniques developed in the project, RESERVE experts have prioritised the following updates to the existing NCs:

- Introducing a definition of Rate of Change of Frequency (RoCoF)
- Reducing the slicing in frequency measurements
- Limitation requirements for the perturbations injected by RES inverters definition
- Recommending settings for the controlled units definition
- An ICT requirements definition
- Data protection requirements definition
- HVDC systems requirements definition

Benefits

These updates will increase the accuracy of the operation of measurement, protection and automation systems, and will facilitate the implementation of the actions required to build the smart grid using the techniques proposed by RESERVE.



NEW BUSINESS MODEL:
ANCILLARY SERVICE-PROVIDERS

The transition towards up to 100% RES means that ancillary services must be increasingly provided by RES rather than by conventional power plants. On this basis RESERVE proposes a new business model for an Ancillary Service Provider (ASP), who provides ancillary services to TSOs and/or DSOs.

The existing balancing market could organise the trading of both the existing ancillary services Frequency Containment Reserve (FCR, primary control) and Frequency Restoration Reserve (FRR, secondary control). In addition, RoCoF (Rate of Change of Frequency) control services, researched in RESERVE, could be offered on the Fast Control Market, which will be a sub-market of the balancing market, to the operator responsible for network stabilisation. Both reserves will ensure a stable grid and reduced costs for the system operators by decreasing transmission losses. Moreover the ASP will take over the obligation of providing ancillary services for power generators who are not able to meet such obligations using their own resources.

The ASP can provide ancillary services using both its own storage units and those of other energy sources through cooperation with an aggregator or by acting itself as an aggregator.

Value Proposition:

- Providing Grid Stability
- Reducing Costs because of Central Controlling

Key Activities:

- Providing power as Ancillary Service
- Providing Energy as Ancillary Services
- Organising Contact with TSOs

Key Resources:

- Remote Controlled Private Production Systems
- Storage Systems (remote controlled)
- Large Power Plants

FEEDBACK

Feedback from TSOs and DSOs

- Digitalisation is a key aspect in the energy transition process towards up to 100% RES and the Internet of Energy (IoE) will improve the information exchange between the DSOs and TSOs.
- An organised framework for facilitating information exchange at the level of network operators needs to be encouraged at an early stage when implementing the new concepts and solutions of RESERVE.
- The "voice of the customer" needs to be considered when defining the data privacy and data security requirements and solutions.
- European TSOs are interested to promote new ancillary services. The algorithms on which these services will be based should be developed by third parties (such as research institutes or universities) to assure their interchangeability.
- The necessary changes in the regulatory framework need to be accelerated to avoid that in a few years the power systems are filled with converter-based generators not designed to cope with future increasing RES penetration.

Feedback from Policy Makers

- The EC encourages regulators to offer incentives to network operators for providing flexibility.
- A price cap on the energy price in order to facilitate the development of electricity storage is not an option.
- The position of the EC is that it should not impose measures but rather to develop guidelines for best practices and recommendations.

Feedback from Regulatory & Standardisation Bodies

- Storage is an important component of the flexibility concept. The Grid Connection Stakeholders Committee managed by ENTSO-E formed two subcommittees to clarify the storage related aspects: one on storage technologies and the second one on operation combining generation, consumption & storage.
- According to RESERVE information, there are no planned short- or medium-term changes to the existing standards or planned actions for developing new standards to adapt to higher RES penetration.
- Relevant European industry associations including ENTSO-E, EDSO for Smart Grids as well as regulatory bodies like ACER and NRA have confirmed, during several consultations organised by RESERVE in Brussels, Vienna and Bucharest, that Storage System Operators (SSOs) will have a role to play as market participants and storage facilities and information related to their capacity and use are needed.

RESERVE PROFESSIONAL TRAINING COURSE BASED ON PROJECT RESULTS

On the 11-15th of March 2019, the RESERVE training course "Challenges and solutions in future power networks" took place at RWTH Aachen University, Germany.

The target audience of the course was energy system and business professionals, as well as power system engineers and doctoral students in the field of power engineering, automation, control for energy systems or ICT for energy systems.

The topics covered addressed the main challenges of building future power networks with a high share of renewable energy sources, and presented the solutions developed by the RESERVE project. These challenges include issues such as frequency and voltage control and ICT requirements as well as the need for a set of new and modified network codes and ancillary services.

The 5-day course was organised in two parts. In the first part, the challenges of managing the future power network with up to 100% RES integration were analysed and the solutions proposed by RESERVE were presented, while the second part of the course focused on the related technical solutions and it offered the participants the possibility to deepen their knowledge by participating in a range of workshops and laboratory exercises on the course topics.

An online version of the course will be made available shortly. It will be accessible through the project website www.re-serve.eu.

RESERVE training course at RWTH Aachen University, Germany

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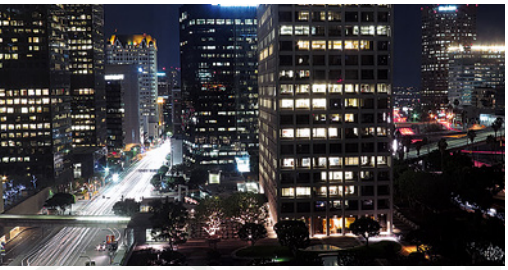

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