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## C2 – Power System Operation and Control

PS2: Operational planning strategies, methodologies and supporting tools

Paper ID_10711

# Smart grid flexibility solutions for transmission networks with increased RES penetration

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## Motivation

- Electricity systems are facing great **challenges to balance the volatility** of **RES**, and thus ensure high continuity and quality of supply.
- The paper presents a **demonstration in Greece**, in the context of FLEXITRANSTORE project, aiming to **test flexibility services** provided efficient controllers and battery storage.

## Method/Approach

- The current paper deals with the **integration of storage to support RES penetration** produced by a wind park in Northern Greece, that is demonstrated in the field.
- The demonstration consists of a battery energy storage system (**BESS**) and a customized controller based on the concept of Active Distribution Node (**ADN**).
- The **BESS System is connected to a 20kV bar**, which is supplied by a 40/50MVA transformer. The BESS power converter installed in the Wind Power Plant (WPP) active substation has a power of 2 MW and an energy capacity of 2 MWh.
- The **Power Conversion System (PCS)** is controlled by an external Controller, including advanced algorithms such as inertial response, predictive algorithms and the demonstration of the convenience of the power firming in WPP.

## Objects of investigation/ Demonstrator description

- Advanced simulations and real-time platforms are developed, in order to **ensure the integration** is fully achieved before shipping the System to the site.
- Advanced algorithms are implemented in the PCS during the discharging and charging to **extend the lifetime of the battery**, increasing the reliability of the BESS.
- Aim of the current work is to present the **design, manufacture and installation of a BESS system** in a 39.1MW wind plant.
- The BESS is based on a 2MW converter and 2MWh batteries and is connected to the 20kV medium voltage grid of a 150kV/20kV substation in Northern Greece, close to the interconnection Greece-Turkey and the PCI (Project of Common Interest) new interconnection Greece- Bulgaria.
- The integration of BESS in the WPP substation contributes to **improve the plant response and increase flexibility**, adding inertial response, predictive algorithms and power firming.

## Challenges - expected benefits – flexibility services envisioned

The demonstrator is deployed in a wind park, in an area with high wind capacity and several wind generation projects. One of its main objectives is to face a series of challenges and benefits related with the transmission and generation energy, i.e.:

- to design and implement an **innovative active substation**, which integrates a BESS, for a WPP, in order **to provide flexible regulation and power management services** to the TSO and to improve its interaction with the transmission network, in an effort to **enhance its regulation, stability and reliability**.
- to enable the usage of energy storage in a WPP active substation to demonstrate **reduction of the resource variability impact on the performance of power systems with significant penetration of RES**.
- to design and implement a complete demonstration project of WPP controller and BESS in the SEE region.

The expected **benefits** and the flexibility services envisioned are summarized as following:

- **Grid Code**: It is highly important for the demonstrator to show how this type of systems provide a lot of benefits to the grid code and the different operational modes that the plants should provide. According to the European Grid ((UE) 2016/631) code for plants below 50MW the substation is considered of type C.
- **Frequency regulation**: The system can be connected to the grid although the grid frequency changes. Moreover, the system helps to regulate the frequency by injecting or limiting the active power.
- **Reactive control mode**: The BESS system is capable of controlling the reactive power in different modes:
  - cos phi control: Maintain a constant cos phi.
  - Q control: Maintain a constant reactive power.
  - V control: Control the reactive power to maintain a defined voltage constant.
- **Low Voltage Ride Through**: The system includes a fully dedicated super-capacitor bank connected in parallel with the control system power supply, in order to ensure the BESS is running without interruption according to the grid code voltage dips. All values (thresholds and timers) are parameterized and will be adjusted according to the Utility and Grid Code requirements.

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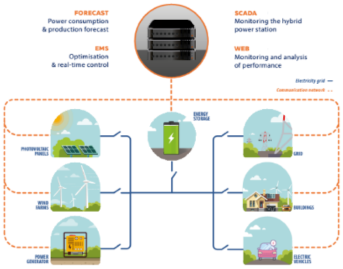
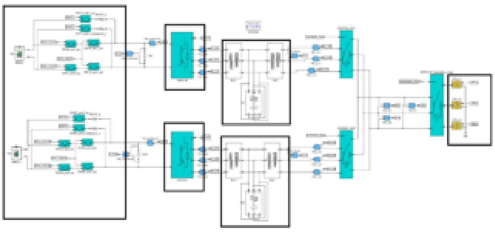
## Technology Description

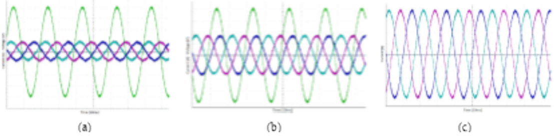
- **Battery charger converter:** The battery charger converter contains two bidirectional converters based on IGBTs technology.
- **Battery Bank:** For the Flexitranstore project 2MWh BoL is required. The implemented battery solution is composed by 15 modules of 140kWh (2,100kWh nominal in total).
- **EMS-PMS System:** The implemented Power Management Systems (PMS/EMS) integrates a powerful hardware and predictive software algorithms that optimizes the production and consumption of the system, effectively controlling the storage units and monitoring the hybrid power station.



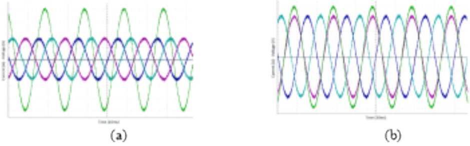

## HiL simulations

- For **the simulation** and **modeling** of the BESS system a **Hardware in the Loop (HiL)** system has been used. Real-time verification system has been used.
- An electric model of the BESS based in MATLAB/Simulink has been implemented in the time simulator, considering the grid conditions and the different parameters of the system. On the other hand, the real control rack, including hardware and software) has been connected to the simulating platform.




*Results for current loop – 1 single power unit, current reference (a) Three phase current reference of 200A, voltage reference generated by the PCS, (b) Three phase current reference of 200A, voltage reference generated by the PCS, (c) Three phase grid current, generated with a reference of 400A*




*Results for battery mode – 1 single power unit, reactive power (Q) reference: (a) Three phase current obtained with a reference of 200kVAr, (b) Three phase current obtained with a reference of -400kVAr*

## Network Reduction

- Since in this project real time control of BESS is implemented, fast and accurate model of the Greek one is needed to analyse system behaviour. Keeping in mind these reasons, **reduced model of the Greek power system is created** such that they can be used in real time simulations.
- In order to control the BESS for grid applications, it is necessary to determine the area in which the BESS has significant impact. This area is regarded as **area of influence (AoI)** in this study.
- To determine the AoI, the **coherency method** was used. The Greek power system has two inter-area modes of 0.8 and 0.94 Hz. Therefore, Greek power system is divided into 3 coherent areas based on inter-area oscillations.
- Next step is to reduce the rest of network to an accurate and simple network. For this purpose, **radial equivalent independent (REI) method**
- In order to validate the reduced system both **static and dynamic studies were conducted**.
- The results show that reduced system is quite accurate to represent full Greek system dynamically as well.
- For static validation, the load flow results of the reduced and original systems are compared. The following Table indicates that load flows of two system are almost the same. Therefore, the reduced system can accurately represent the static behaviour of the full Greek system.

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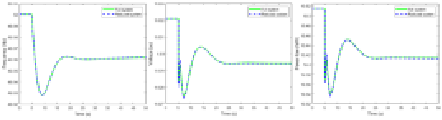
## Network reduction (continue)

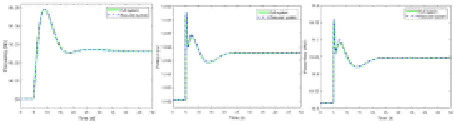
*Load flow of full and reduced Greek system*

| | Full System | Reduced System |
|---|---|---|
| Voltage magnitude at 10732 KNSANTA HV | 1.03 (p.u.) | 1.03 (p.u.) |
| Voltage angle at 10732 KNSANTA HV | 1 (deg) | 1 (deg) |
| Voltage magnitude at 10631 ALEXNDRO | 1.03 (p.u.) | 1.03 (p.u.) |
| Voltage angle at 10631 ALEXNDRO | 0.4 (deg) | 0.4 (deg) |
| lne_10732_10933_1 line active power | 21.3 (MW) | 21.3 (MW) |
| lne_10732_10933_1 line reactive power | -13.9 (Mvar) | -13.9 (Mvar) |
| lne_10131_10631_1 line active power | 16.5 (MW) | 16.5 (MW) |
| lne_10131_10631_1 line reactive power | -10.3 (Mvar) | -10.3 (Mvar) |

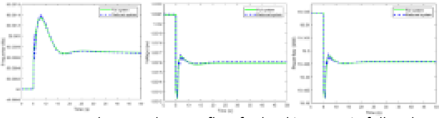
- Next Figures depict the results of the dynamic validation, considering three different cases.



*Frequency, voltage and power flow for load increase in full and reduced Greek system – Dynamic validation (Load lod_10231_1 is increased by 300%)*



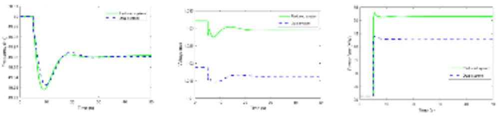
*Frequency, voltage and power flow for load increase in full and reduced Greek system - Dynamic validation (Load lod_10631_1 is disconnected)*



*Frequency, voltage and power flow for load increase in full and reduced Greek system - Dynamic validation (Line lne_10131_10631_1 is tripped)*

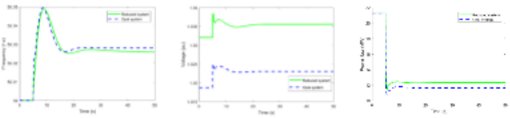
## Reduced Network Validation in RT Simulator

- The developed real-time models are used to emulate the dynamic behaviour of the Greek power system.
- In order to validate the Greek model developed, a **comparison of the dynamic simulations and results** has been carried out. The following events were considered:
  - **Event 1:** An increasing of 300% of the demand in node ORESTIAD. The demand suddenly increases from 22,447 MW to 67.3 MW and from 13,918 Mvar to 41,754 Mvar, originating an under-frequency scenario.
  - **Event 2:** Disconnection of the demand connected to node ALEXNDRO. The demand to disconnect has a capacity of 48 MW and 30 Mvar.
  - **Event 3:** Line trip in line DIDIMOTE – ALEXNDRO.



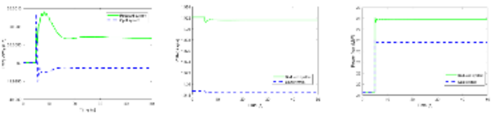
(a) (b) (c)

*DIgSILENT Power Factory and ePHASORSIM (a) frequency Response comparison of Greek grid for event 1, (b) voltage behaviour comparison of Greek grid for event 1, (c) line power flow in KNSANTA HV – IASM_T1 comparison of Greek grid for event 1*



(a) (b) (c)

*DIgSILENT Power Factory and ePHASORSIM (a) frequency Response comparison of Greek grid for event 2, (b) voltage behaviour comparison of Greek grid for event 2, (c) line power flow in KNSANTA HV – IASM_T1 comparison of Greek grid for event 2*



(a) (b) (c)

*DIgSILENT Power Factory and ePHASORSIM (a) frequency Response comparison of Greek grid for event 3, (b) voltage behaviour comparison of Greek grid for event 3, (c) line power flow in KNSANTA HV – IASM_T1 comparison of Greek grid for event 3*

## Conclusions

- The paper presents the demonstration in Greece, aiming to **test flexibility services** provided efficient controllers and battery storage.
- The demonstration includes real world installations on the actual electricity grid installations and extensive set of planning, simulation and testing, in order to ensure the evolution of the technology to a high Technology Readiness Level (TRL).
- The **innovative controller and battery storage** have been planned designed and tested to **provide flexibility services** through a WPP installation, promoting **new business models for RES producers**.
- The products have been designed, developed and prepared for the actual network environment.
- By the end of FLEXITRANSTORE project, similar technologies will be installed in other transmission networks in SEE to demonstrate **scalability and replicability** of the developed innovations.

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