MIGRATE – MASSIVE INTEGRATION OF POWER ELECTRONIC DEVICES

Aalborg, Denmark – 4th June 2019
• **Introduction to the MIGRATE project**
  *Marta Val Escudero (EirGrid)*

• **WP1: Mitigation approaches for power system stability under high Power Electronics (PE) penetration**
  *Dr. Sven Rüberg (TenneT TSO)*

• **WP2: Wide-Area-Controls for improved system stability. Results of pilot tests in Iceland**
  *Douglas Wilson (GE Power)*

• **WP3: From grid-forming definition to experimental validation with a VSC**
  *Guillaume Denis (RTE)*

• **WP4: Protection system design for a future power system with high penetration of Power Electronics (PE)**
  *David Lopez Corton (REE)*

• **WP5: Power Quality Aspects in Future Power Systems**
  *Jako Kilter (Elering)*

• **Open discussion**
INTRODUCTION TO THE MIGRATE PROJECT

Marta Val Escudero (EirGrid)
FACTS

– Horizon 2020 – LCE-6: Transmission Grid & Wholesale Market
– Funding Scheme: Collaborative project
– Type of Action: Research & Innovation

– Acronym: MIGRATE

Massive InteGRATion of power Electronic devices

– Framework Conditions:
  + Publication Date: 2013-12-11
  + Deadline Date: 2015-05-05; 17:00:00 (Brussels local time)
  + Main Pillar: Societal Challenges
  + Duration of Project: 48 month (Project Start on 1st January 2016)
  + Budget: 17.9 mio. € for the consortium (16.8 mio.€ Horizon 2020 founded)
OBJECTIVE

The objective of MIGRATE is:

To develop and validate innovative, technology-based solutions in view of managing the pan-European electricity system experiencing a proliferation of Power Electronics (PE) devices involved in connecting generation and consumption sites.

This overarching goal is split into two components combining two time horizons:

in the short to medium term, incremental technology-based solutions are needed to operate the existing electric HVAC system configuration with a growing penetration of PE-connected generation and consumption, based on novel methods and tools,

in the long term, breakthrough technology-based solutions are needed to manage a transition towards an HVAC electric system where all generation and consumption is connected via 100% PE, based on innovative control algorithms together with new grid connection standards.
OVERARCHING GOAL

Transit zone
System stability is addressed within the existing framework: controllers and grid codes

Inclusion

Improvement of system stability within the existing framework

Technology leap
System stability is addressed with breakthrough methodologies and controllers with modified grid codes
EXPECTED IMPACT

Support to facilitate a low carbon energy system by

• **Maximisation** of the amount of Renewable Energy Sources installed in the system while keeping the system stable.

• **Anticipation** of future potential problems and challenges.

• **Clarification** of the need of new control/protection schemes and possibly new connection rules to the grid

MIGRATE will provide requirements for future measures, methods and tools for a secure operation of the upcoming converter dominated power system.
THE CONSORTIUM

Estonia  TTU  elering
Iceland  LANDSNET
Finland  FINGRID
Germany  TENNET  amprion
Scotland (UK)  SP ENERGY NETWORKS
England (UK)  MANCHESTER
Ireland  EIRGRID GROUP
Netherlands  TENNET  TU Delft
France  ABB ETIERS  Schneider Electric  RTE
Switzerland  ETH Zürich
Slovenia  ELENA  ELES
Italy  ENEL  Terna
Spain  CIRCE  RED ELECTRICA DE ESPAÑA
### TSO PARTNERS

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<tr>
<th>Participant No.</th>
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<tr>
<td>1 (Coordinator)</td>
<td>TenneT TSO GmbH</td>
<td>Germany</td>
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THE GOVERNANCE

European Commission
General Assembly
Advisory Board
Project Coordinator
Executive Board
Reference Group

WP1
WP2
WP3
WP4
WP5
WP6
WP7
WP8
THE WORK PACKAGES

WP1
Power System stability issues under high penetration of PE

WP2
Real Time Monitoring and Control

WP3
Control and operation of a grid with 100% converter based devices

WP4
Protection schemes in transmission networks with high PE penetration

WP5
Power quality in transmission networks with high PE penetration

WP6 – Exploitation

WP7 – Communication and Dissemination

WP8 – Management
MITIGATION APPROACHES FOR POWER SYSTEM STABILITY UNDER HIGH PE PENETRATION

Preliminary Results from the MIGRATE WP1

Dr. Sven Rüberg, TenneT TSO
AGENDA

1. Working Package Overview
2. Preliminary Results
3. Conclusions / Outlook
WORKING PACKAGE OVERVIEW
Development of Mitigation Approaches to Address Power System Stability Issues Under High Penetration of Power Electronics

1. To identify and prioritise the **stability-related issues faced by the TSOs** considering different network topologies, geographical locations and penetration levels of PE (generators, HVDC converters, FACTS, loads);

2. To develop **novel approaches and methodologies** able to analyse and mitigate the impacts of PE penetration on power system stability based on simulations, laboratory scale experiments and PMU measurements methods (data supplied by WP2);

3. To propose **control strategies so as to further tune and coordinate existing system controls** in order to maximise the penetration level of PE considering the current operating rules, the existing control and protection devices and the available degrees of freedom in the network codes (RfG and HVDC grid codes as well as the DCC);

4. To validate the use of a **monitoring approach** of the PE penetration **based on-line PMU measurements** methods developed in WP2.
WP1 is structured into 8 strategic tasks:
PRELIMINARY RESULTS
PRELIMINARY RESULTS: DELIVERABLE D1.1

D1.1: Report on Systemic Issues

– Summary of existing requirements for grid connected PE
– Preliminary assessment for PE capabilities
– Current and arising issues
  + Questionnaire to 33 TSO and literature survey
  + 11 issues identified: low inertia, PE resonance, transient instability, etc.
  + Issue prioritization
– High-level description of the model problems

--> D1.1 is public! <--
www.h2020-migrate.eu
PRELIMINARY RESULTS: CURRENT AND ARISING SYSTEMIC ISSUES

- MIGRATE TSOs were asked to rate each issue in three dimensions.

- As a result, the issues were ranked:

  1. Decrease of inertia
  2. Resonances due to cables and PE
  3. Reduction of transient stability margins
  4. Missing or wrong participation of PE-connected generators or loads in frequency containment
  5. PE controller interaction with each other and passive AC components
  6. Loss of devices in the context of fault-ride-through capability
  7. Lack of reactive power
  8. Introduction of new power oscillations and/or reduced damping of existing power oscillations
  9. Excess of reactive power
  10. Voltage dip-induced frequency dip
  11. Altered static and dynamic voltage dependence of loads
## Preliminary Results: Grouping of Research Targets

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<tr>
<th>Model Problem</th>
<th>Stability Issue</th>
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<td><strong>Frequency stability</strong></td>
<td>Decrease of inertia</td>
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<td>Missing or wrong participation of PE-connected generators and PE-connected loads in frequency containment</td>
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<td><strong>Transient rotor angle stability</strong></td>
<td>Reduction of transient stability margins</td>
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<td><strong>Short-term voltage stability</strong></td>
<td>Loss of devices in the context of fault-ride-through capability</td>
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<td>Lack of reactive power</td>
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<td><strong>Controller interactions</strong></td>
<td>PE controller interaction with each other and passive AC components (low-frequency range)</td>
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PRELIMINARY RESULTS:
GRID FOLLOWING VS. GRID FORMING CONTROL

**Grid following control:**
- dq control of current fed into the system
- decoupled control of P and Q
- needs PLL
- needs voltage at the PCC in order to deliver P and Q
- hence, cannot operate at 100 % PE penetration

**Grid forming control:**
- control of voltage magnitude and frequency/phase
- slight coupling between P and Q
- does not need a PLL
- can blackstart a power system
- hence, can theoretically operate at 100 % PE penetration
PRELIMINARY RESULTS: AGGREGATED 29-BUS MODEL OF GB (1/2)

Case Study with grid following control only

classifications: stable, unstable, marginally stable

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PRELIMINARY RESULTS:
AGGREGATED 29-BUS MODEL OF GB (2/2)

- Case Study with some PE units performing grid **forming** control

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<th>SG (MVA)</th>
<th>WND (MVA)</th>
<th>Total MVA</th>
<th>PE in % (MVA)</th>
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**Grid Forming WND in %** 44,5
**Classic Controlled WND in %** 55,5

*MIGRATE Panel Session at the 2019 CIGRE Symposium Aalborg*
CONCLUSIONS / OUTLOOK
CONCLUSIONS / OUTLOOK: KEY TAKE-AWAYS

- With increasing levels of PE penetration, the stability and dynamics of a power system will change significantly
- PE interfaced generators will have to actively take part in power system control
- For the given case study,
  - a maximum PE penetration of 68 % was identified if we continue installing grid following PE units only
  - the maximum PE penetration can be significantly increased if some of the PE units perform grid forming control
- Also, grid forming control
  - can operate at extremely low short-circuit ratios (below 1)
  - can inherently balance active-power mismatch (-> frequency stability)
  - has less tendency towards control interaction with other local PE units
CONCLUSIONS / OUTLOOK: NEXT STEPS

- Further improvement of grid forming control principle
  - Increased stability with 100 % PE in more realistic power systems
  - Integration of important auxiliary control functions
- Test of grid forming control in a more realistic/larger power system model
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WP2: WIDE-AREA-CONTROLS FOR IMPROVED SYSTEM STABILITY – RESULTS OF PILOT TESTS IN ICELAND

Douglas Wilson (GE Power)
INTRODUCTION

Managing Low Inertia Grid Scenarios

Enabling higher penetration of low inertia renewable generation using wide area monitoring and control

The Inertia Challenge

Measuring Area-Inertia with PMUs

Resolving by Locational Fast Response (or constraints)

MIGRATE experience of containing frequency in Icelandic grid through fast control in intact and islanded conditions
**EFFECT OF SPARSE CENTRES OF INERTIA**

Iceland shows frequency & angle divergence between centres of inertia

- **A** T=0s  Industrial load #1 reduction (first stage)
- **B** T=0.2s  Industrial load #1 reduction (second stage)
- **C** T=0.36s  Industrial load #1 trip
- **D** T=1.1s  Area angles separated by 60°, result in high E-W power. One route opens by special protection
- **E** T=1.2s  Areas accelerate away from each other; synchronism is lost and system islands

Loss of large load causes rapid, unequal rise in frequency → phase angles diverge → Islanding
EFFECT OF SPARSE CENTRES OF INERTIA

Great Britain: Regional ROCOF close to loss of mains & increased islanding risk.

Frequency change takes time to propagate → Angles diverge → Stability risk

ROCOF hits loss-of-mains limits in north & south

Average system RoCoF within GB 0.125Hz/s limit, but threshold exceeded in both the north & south GB (not Midlands). Risk of regional DER tripping, or in extreme case, loss of angle stability in network.
Effective Area Inertia: measurable KPI for frequency containment

Large generators with inertia limit Rate of Change of Frequency (RoCoF) after a disturbance. Displacing inertial generators with non-inertial power electronic sources means that other contributions to frequency stability are important. Effective Inertia is a measure of combined inertia-like effects of rotating machines, passive load responses, active generator controls etc.

Rapid localised frequency changes in areas with low inertia can cause distributed generator tripping and islanding. Effective Area Inertia relates changes in RoCoF and power imbalance for an area, to manage grid stability in disturbances in that area.

\[
\begin{align*}
\frac{df_a}{dt} &= \text{Average Rate of Change of Frequency in Area} \\
\Delta p_e &= \text{Electrical power to accel/decal rotating inertia} \\
\Delta p_{ni} &= \text{Power to non-inertial elements e.g. load} \\
\Delta p_b &= \text{Net power across area boundary} \\
\Delta p_b &= \Delta p_e - \Delta p_{ni} \\
H_{EA} &= \frac{\Delta p_b(t)}{2\frac{df_a(t)}{dt}}
\end{align*}
\]
MEASURING THE EFFECTIVE AREA INERTIA

- MIGRATE explored event-based and continuous effective area inertia extraction techniques.
- Example shows section of data used to compute effective inertia using correlated changes
- **Area RoCoF** for Centre of Inertia (COI)
- **Net Boundary Power** across the area boundary

\[ H_{EA} = \frac{\Sigma p_b(t)}{2 \frac{df_a(t)}{dt}} \]

Continuous inertia measurement (1 week)

**Compare with estimates using expected influences:**
rotating inertia & load. \((a_1, a_2)\) statistically determined

**Linear model**
\[
\text{Linear model} = a_1 . (\text{rotating inertia}) + a_2 . (\text{load})
\]

**Forecast** through machine learning applied to \(H_{EA}\) with generation/demand predictor variables
Mitigating low inertia frequency & islanding risks

**Angle Difference**
- Angles swing apart during disturbance → islanding risk
- Act in location to return angles to system mean angle

**Frequency**
- Disturbance Frequency accelerates in proportion to (MW loss) / (inertia). BUT not uniform across network

**Zones** Centres of inertia; islanding may occur between zones, not (successfully) within zones. A single Aggregated Angle and Frequency per zone shared with all control points.
RESPONSE IN PROPORTION TO POWER IMBALANCE

Connected effective inertia relates System ROCOF to P Imbalance

Fast initial response, self-correcting

Initial event leads to steep RoCoF

Ramping response stabilises frequency

Step responses slow RoCoF in < 1s

Resources deployed in proportion to System RoCoF & System Inertia for the currently-connected area(s)

Responses subject to location-enabling

- **High Frequency** response enabled with lagging angle/higher freq*
- **Low frequency** response enabled with leading angle/lower freq*

* For own Area relative to mean angle/frequency of the connected part of the system
**LOCATIONAL FFR RESOURCES**

- **Control Centre**
  - Data Concentrator for PMU data
  - Control Room visualisation
  - Administration of PhasorControllers
  - Testing & trials

- **East Iceland Fish Factory Load Shed (x6 plants)**
  - PhasorController
  - PMU data IN, 61850 GOOSE OUT to 6x satellite I/O
  - Factories link satellite I/O to load breaker

- **Hrauneyjafoss (HRA) Fast Ramp**
  - PhasorController
  - PMU data IN, Dig Out
  - Governor acts on RAMP DOWN & WICKET GATE CTRL

- **ISAL Smelter Load Control**
  - PhasorController
  - PMU data IN, 61850 GOOSE OUT
  - 1x interface unit to I/O → plant control

- **Sigalda (SIG) Intelligent Split**
  - PhasorController
  - PMU data IN, Dig Out
  - Open bus tie breaker
  - Create more balanced island

- **NAL Smelter Load Control (similar to ISAL control)**

- **Geothermal governor control (planned)**
  - PhasorController
  - Controlled fast ramp & islanding control

- **Operational now**
- **Under development**
OPERATIONAL EXPERIENCE

Large load loss BEFORE WAC IMPLEMENTATION

- Frequency (Freq [Hz]):
  - Pre-implmentation data

- Generation (Gen [MW]):
  - Pre-implmentation data

- Load (Load [MW]):
  - Pre-implmentation data

Graphs showing the impact of load loss on frequency, generation, and load before WAC implementation.
OPERATIONAL EXPERIENCE

Compare same large load loss AFTER WAC IMPLEMENTATION

Load response in <0.5s, reduces frequency peak.

Hydro fast ramp start at 3.5s, replaces fast temporary load response. Rate & volume greater than primary control.
OPERATIONAL EXPERIENCE

Locational element blocks remote response until it improves stability
OPERATIONAL EXPERIENCE

Over 30 test events, including 2017 activations

In 2 ½ years from go-live to present time, around 70 activation triggering events.

“The activations have all been in time and helpful for the stability of the grid.”

Birkir Heimisson
Manager for Smart-Grid Development
Landsnet
NETWORK INFRASTRUCTURE

PMU+Communication latency <100ms; Overall trigger time <0.5s
Grid-sensitive frequency and stability/islanding enhancement

Frequency response resources coordinated for total frequency response.
- Rapid event-triggered ($k_1 \Delta P_{loss}$)
- Rapid freq-control ($k_2 \Delta F$; deadband)
- Normal freq-control ($k_3 \Delta F$ with delay)

Aggregation enables many diverse resources to participate in service provision, including variable generation & demand response

Delivering overall response that is:
- Proportionality to event
- Discriminating real system events
- Enhancing grid stability
- Predictable aggregate response

UNIFIED TOTAL POWER BALANCING RESPONSE USING DIVERSE RESOURCE
CONCLUSION OF OPERATIONAL EXPERIENCE

Wide area control is working well

- Fast acting (<0.5s) & reliable with fault-tolerant distributed control. Handles complex multi-event sequences.
- Frequency containment improved: ~0.2-0.4Hz; e.g. trip size previously causing >52Hz contained at 51.8Hz
- Reduced islanding probability & impact with sparse inertia: 4 events expected to cause islanding remained intact
- More connection capacity: 107MW load able to connect with WAC scheme
- Landsnet plans to extend to more sites & new use cases

Enables flexible fast frequency services from existing plants

- Diverse loads & generators can contribute. New service capability easily added.
- Cost effective – no new capital equipment – major saving over Synchronous Condensers or Battery Storage
- Improvements achieved without grid reinforcement (unlike Synch Condenser or Battery)

General applicability

- Could be applied in other systems (incl large interconnections) with straightforward revisions
OUTLOOK FOR LOCA TIONAL FFR & ISLANDING CONTROL IN ICELAND

Further rollout planned to operate within „Frequency Envelope“ to be defined in each region

Examples of resources considered

• Geothermal Power Stations (HF) around Iceland (work in progress)
• Hydro fast ramp extended to more units; rolling out to all three HRA
• Alcoa smelter, East Iceland, is currently controlled using an older load reduction scheme, but could be adapted to a ramping response.
• Data centres and other energy-intensive commercial loads (non-firm connections - work in progress)
• Emerging Electric Vehicle fleet and charging points

Commercial arrangements for services are being explored
MIGRATE WP3:
FROM GRID-FORMING DEFINITION TO EXPERIMENTAL VALIDATION WITH A VSC

Guillaume DENIS, Thibault PREVOST, RTE, 4th June 2019, Aalborg

guillaume.denis@rte-france.com
OVERVIEW OF WP3 CHALLENGE

Synchronous machines create voltage waveforms with the same frequency.

Converters measure the grid frequency.

Converters provide active and reactive power at the measured frequency.
OVERVIEW OF WP3 CHALLENGE

MIGRATE: Requirement for systems with high share of PE-interfaced devices:

*Acceptable level of stability while keeping costs under control*

WP3: Control and operation of **large transmission systems** with **100%** converter-based devices

*“to be forced to reset our brain”*

The requirement for grid forming inverters
WP3: THE PROBLEM ANALYSIS IN 2016 [D3.1]

**Ideal electrical sources**
- 3ph - Voltage Sources
- Perfectly synchronized at $f_n$
- Infinite power supply
- Infinite energy storage

**Physical constraints of PE-based system**
- Limited Bandwidth and Current of VSC
- No communication
- Limited power and finite energy
- Topology imposed and variable
- Compatibility with other sources (SG, gf, IM)

[D3.1] « Description of system needs and test cases », TSOs of MIGRATE project, Deliverable 3.1, 2016
## WP3: THE PROBLEM ANALYSIS 2018 [D3.2] [D3.3] [D3.4]

### Ideal electrical sources
- 3ph - Voltage Sources
- Perfectly synchronized at $f_n$
- Infinite power supply
- Infinite energy storage

### VSC Grid-Forming Function:
- As close as possible from Voltage Source
- Stable synchronization around nominal frequency
- Decentralized Load Sharing services
- New operational rules

### Physical constraints of PE-based system
- Limited Bandwidth and Current of VSC
- No communication
- Limited power and finite energy
- Topology imposed and variable
- Additional constraint of WP3
  - Compatibility with other sources (SG, gf, IM)

[D3.2, L2EP 2018], [D3.3, ETH 2018], [D3.4, UCD 2018]
OUTPUTS OF WP3

1. Results on grid-forming control design => Performance and Stability
2. Results on current limiting strategy => Hardware protection
3. Results on load-share services redefinition => New ancillary services
4. Results on Irish system simulation with 100 % PE => New operating rule
OUTPUTS OF WP3

1. Results on grid-forming control design => Performance and Stability
2. Results on current limiting strategy => Hardware protection
   + Problem of grid-current sensibility
   + Description of current strategy limitation by virtual impedance + current saturation
   + Experimental results
3. Results on load-share services redefinition => New ancillary services
4. Results on Irish system simulation with 100 % PE => New operating rule
THE GRID-FORMING FUNCTION

Stiff voltage source behavior

≈50 Hz

Synchronizes with other sources (EnR, MS, GF)

Current-limiting strategy

Islanding

≈50 Hz

SG

SG

Echanges EDF/ RTE - 21 mai 2019
THE GF FUNCTION: EXAMPLE OF TEST-CASES

Magnitude and Phase angle jump

TEST 2-A-1 : SRC=20, $K_{sc}$ closes, $K_{line}$ open 150 ms after
THE GF FUNCTION: EXAMPLE OF TEST-CASES

Figure 32: DC signals of a single converter during a short circuit fault and subsequent line opening. A short circuit fault occurs on one of the lines at \( t = 1.5 \) s and is cleared by disconnecting the line after 150 ms.

Figure 33: AC signals of a single converter during a short circuit fault and subsequent line opening. A short circuit fault occurs on one of the lines at \( t = 1.5 \) s and is cleared by disconnecting the line after 150 ms.
THE GF FUNCTION: EXAMPLE OF TEST-CASES

Interoperability on 3-bus Benchmark

$K_3$ opens, $K_{sc}$ closes, $K_{line}$ open 150 ms after,
**Key finding:**

1. Stability and robustness are achieved if, after grid disturbance, the response of the imposed voltage magnitude and frequency is «slow enough»

2. In small-signal, all the grid-forming control behave similarly, as seen from their output.

3. Interoperability of independently designed controllers

**Events**
- $t = 0.5\ s$: line from PCC1 to PCC3 disconnected
- $t = 5\ s$: short circuit near PCC1
- $t = 1.65\ s$: short circuit is cleared
**PROBLEM OF GRID-SENSITIVITY OF GRID-FORMING**

*Slow voltage source are subject to overcurrent during stressing events*

**Problem:**

![Diagram of VSC+LCL with L_line and I_L](image)

- $VSC+LCL_1$
- $L_{line}$
- $I_L$
- $P_L = 120MW$

**Proposed solution:** Current loop saturation during first peak and virtual impedance afterwards

$\Rightarrow$ Validated concept in simulation, currently tested experimentally
All the controls and test cases have been made open source.

https://doi.org/10.4121/uuid:e5497fd2-f617-4573-b6d5-1202ebae411d
1. **Grid-forming function performances have been unified** and defined from a system level perspective (techno-agnostic). The Grid-forming function gather the necessary conditions of a source to ensure proper and stable definition of **voltage waveform that resist to small-disturbance**, throughout a multi-sources grid.

2. **Suitable current-limiting strategy can protect sensitive power-electronics devices** during stressful event without compromising their grid-forming function and without requiring costly oversizing.

3. The last year of the project aims at providing **grid-codes requirements guidelines**
NEW CHALLENGES: 1) TRANSIENT STABILITY

Droop based Grid-forming VSC during 3ph-fault. [D3.2 L2EP 2018]
NEW CHALLENGES: 2) FRT REQUIREMENTS?

Support Nominal Voltage as long as $I \leq I_{\text{max}}$, or stay $I_{\text{max}}$

Stay Synchronized

- Back to steady-state in 200ms
- Breaker remain close
- No control switch
NEW CHALLENGES: 3) UNBALANCE FAULT

The current magnitude (yellow) has a negative sequence component, and thus, it triggers periodically the threshold virtual impedance, inducing high distortion.
Thank you for your attention!
AGENDA

1. OBJECTIVE AND STRUCTURE OF THE WORK PACKAGE
2. OVERALL PROGRESS
3. MAIN RESULTS AND ACHIEVEMENTS
4. NEXT 18-MONTH PLAN
5. CONCLUSION
Protection schemes in transmission networks with high PE penetration

– Objectives:

+ Provide a detailed insight into the ability of present protection practices to properly operate during system disturbances under very high penetration of PE.

+ Evaluate and test emerging technologies together with new system protection strategies and develop new ones in order to overcome the identified threats when operating at 100% of PE penetration.

+ Give recommendations for the design of protection schemes for future power systems with very high penetration of PE.
Describe the work performed

– Deliverables

D 4.1  • Grid and PE models validated for protection studies to perform HiL tests with RTDS
       • M12

D 4.2  • Limitations of present power system AC protection schemes and System Integrity Protection Schemes (SIPS) to properly operate in systems with high penetration of PE during AC faults
       • M21

D 4.3  • New developments, technologies and solutions proposed to overcome constraints identified in task 4.2
       • M34

D 4.4  • Analysis of the behaviour of the new protection concepts proposed in task 5.3 in a HiL facility with real protection equipment
       • M46

D 4.5  • Power system design for a secure system with high penetration of PE
       • M48
WP4 – MAIN RESULTS AND ACHIEVEMENTS

– During year 2017, problems with present protection systems in scenarios with high PE penetration where studied.

– The study included line differential protection, distance protection and ground differential protection regarding short circuit protection and Under Frequency Load Sheeding (UFLS), Under Voltage Load Sheeding (UVLS) and Power Swing Tripping (PST) regarding System Integrity Protection Schemes (SIPS).

– Results showed that distance protection is the most affected protection function regarding short circuit protection and that UFLS, UVLS and PST will need to adapt to this new scenario.
WP4 – MAIN RESULTS AND ACHIEVEMENTS

– As a result of the conclusions obtained during year 2017, WP4 was focused on the following areas:

+ Proposal of a new UFLS scheme
+ Proposal for the application of a new PST scheme based on angle measurements obtained from Phasor Measurement Units
+ Proposal of improvements for faulted phase identification in distance protection
+ Proposal of improvements for fault detection in distance protection
+ Assessment of the impact of possible future requirements in the behaviour of the protection system

![Diagram showing frequency threshold and time delays for UFLS]
WP4 – MAIN RESULTS AND ACHIEVEMENTS

SLG, LL, LLG faults applied three times each at 0%, 50%, 70%, 90%, 100%

RELAY
RELAY
RELAY
RELAY
RELAY
RELAY
WP4 – MAIN RESULTS AND ACHIEVEMENTS

– New faulted phase selector and fault detector for scenarios with high PE penetration
  • Despite the control strategy chosen, following stages can be distinguished from the initial steady state until a new steady state after the clearance of the fault:

  ![Diagram showing stages: Initial steady state, Fault inception (7-20 ms), Transition period (20-40 ms), Steady state fault contribution, Fault clearance, Final steady state]
WP4 – MAIN RESULTS AND ACHIEVEMENTS

Type 4 WT current contribution
AB fault

Current Waveform: A, B, C

Voltage Waveform: A, B, C
– Task 4.4. Proof of concepts (M34-M46) [Lead: Schneider, Participants: REE, Elering, UoM, CIRCE, Schneider] [Deliverables: D4.4] [Milestone: M4.4]

– The new protection concepts developed in Task 4.3 will be further studied by performing HiL tests with real protection equipment supplied by Schneider in order to check the feasibility (both technical and economic) of the proposed solutions. In a first step, the performances of the proposed schemes and algorithms Task 4.2 will be verified. Hardware in the loop techniques (HIL) will be used, by simulations with the RTDS and using the grid models defined and developed in Task 4.1. In a second step, the new protection developed in Task 4.3 will be tested in the same manner in order to verify if they still fulfil protection requirements with any PE penetration, including 100%.

– The work to be carried out in Task 4.3 is as follows:

– Description of the test protocol and cases to be tested;

– Integration of the new solutions developed in Task 4.3 in the HiL facility based on the power system model implemented in the RTDS in Task 4.1;

– Perform HiL tests of the new protection concepts proposed in task 4.3;

– Check that the new protection concepts proposed in Task 4.3 fulfil the needed protection functions for any PE penetration and identify the necessary modifications and improvements required for the existing protection system.
Task 4.5. Power system design for a secure system with high PE penetration (M47-M48) [Lead:REE, Participants: Elering, RTE, UoM, TUDelft, CIRCE, Schneider] [Deliverables: D4.5]

In Task 4.5, the outputs of Tasks 4.2 to 4.4 will be further analysed so as to give recommendations for the design of protection schemes for power systems with high penetration of PE. The recommendations will cover different penetration levels and will address protections against short circuits, System Protection and Communication systems for AC, DC and hybrid DC/AC networks.

The work to be carried out in Task 4.5 is as follows:

- Analysis of the results obtained in tasks 4.2, 4.3 and 4.4;
- Assessment of the outputs of Tasks 4.3 and 4.4 for the proposed protection equipment (SIPS and short circuit protections);
- Assessment of the feasibility of the proposed solutions;
CONCLUSION

- Two new and innovative short-circuit protection algorithms for scenarios with high PE penetration have been developed.
- A new and innovative UFLS scheme for scenarios with high PE penetration have been developed.
- An new PST scheme algorithm based on the application of PMU has been developed for scenarios with high PE penetration.
- Schneider will integrate new short-circuit protection algorithms in a real protection platform and will carry out tests in order to verify the technical and economical feasibility of the solutions proposed.
- REE will provide a document of guidelines for the design of future power system protection schemes for scenarios with high PE penetration including an analysis of the impact of future grid codes.

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QUESTIONS?

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WP5: POWER QUALITY ASPECTS IN FUTURE POWER SYSTEMS

Jako Kilter (Elering)
AGENDA

1. OBJECTIVE AND STRUCTURE OF THE WORK PACKAGE
2. OVERALL PROGRESS
3. MAIN RESULTS AND ACHIEVEMENTS
4. CONCLUSION
WP5 OBJECTIVES

• The increasing penetration of PE-interface renewables has already resulted in PQ challenges as evidenced by harmonic distortion, voltage sags and other disturbances.

• PE devices are one of the major sources of PQ disturbances in power systems but they are also very sensitive to PQ disturbances themselves.

• MIGRATE WP5 is dedicated to investigate power quality in transmission networks with high PE penetration.

Main objectives

– Evaluation of PQ related issues
– Developing numerical models of PE devices for PQ studies
– Evaluation of PQ level in future PE rich power networks
– Mitigation options for keeping PQ levels within allowed values
– Use of available assets for PQ monitoring
POWER QUALITY PHENOMENA RELATED TO PE

- **Voltage dips and Temporary Over-Voltage**
- **Harmonic distortion** (PE harmonic injections, device susceptibility to voltage harmonics, grid resonance, poor controllers performance causing excessive harmonic distortion)
- **Supraharmonics**
- **Flicker and voltage fluctuation**
- **Harmonic resonance**
- **Voltage Unbalance**
- **Voltage variation**
- **Frequency variation**
- **Frequency fluctuations**

Main focus of WP5
WHAT ARE THE MAIN PQ ISSUES?

Results from WP5 D5.1 Questionnaire (answers from European TSOs), 2016
WP5 DELIVERABLES

2016

2017

2018

2019

- Identification of current and arising Power Quality issues in Transmission Systems
  - Questionnaire – European TSOs
  - Evaluation of influence of harmonics on PMU accuracy

Publically Available Report

https://www.h2020-migrate.eu/downloads.html
WP5 DELIVERABLES

2016

2017

2018

2019

- Detailed (EMT) and reduced (Frequency Domain) models of PE devices for PQ studies

Publically Available Report

https://www.h2020-migrate.eu/downloads.html
PE DEVICES MODELS

– Models developed for:
  + High voltage direct current system (HVDC),
  + Static compensator (STATCOM),
  + Static-var compensator (SVC),
  + Wind-turbine generators (WTG type 3 and 4),
  + Solar photovoltaics (PV) and
  + Battery storages (BS).

– For each device, three types of models with different level of detail and complexity have been developed: the electromagnetic transient (EMT) model, the average RMS model and the harmonic load-flow model (frequency domain).
A representative topology for each PE device (amongst a wide variety of different topologies and implementations currently available) has been selected. This approach has been adopted in order to provide a generic, yet representative, model and more importantly, to propose a methodology for EMT modelling of PE devices for PQ studies.

Harmonic load flow models developed by “scanning” the EMT models in various operating points.
WP5 DELIVERABLES

- Development of **probabilistic methodology and tools** for analysis of PQ disturbances
- Visualisation tool for propagation of PQ disturbances
- Assessment of PMUs for PQ monitoring
- Assessment of harmonic propagation
- Influence of PQ on PE and PE on PQ
- PQ legislation in Europe (Grid Codes)

Publically Available Reports

https://www.h2020-migrate.eu/downloads.html
PQ VISUALISATION TOOL - ODIN

- PQ measurement data
- Other data input available
- PMU measurement data

Publically Available Tool
ca 50% of TSO see possibilities in using PMUs for PQ

Results from WP5 D5.1 Questionnaire (answers from European TSOs), 2016
PMU-S FOR PQ

• It is possible to use PMU data for some indicative steady-state PQ assessment
• Frequency and voltage testing show that errors are below standard criteria
• For higher harmonics measurement PMUs with special modules or algorithms have to be used
• Various PMUs behave differently
• Use suitable transducers at transmission system level
• Compliance to EN 61000-4-30 Class A
All TSOs responded that **PQ requirements** are **defined** in their system.

Requirements for PQ in Europe are mostly defined in **national legislative acts**.

Most TSOs have documented **procedures** for defining/setting **limits** for new **customers** and for **compliance verification**.

The main references used/followed for defining PQ are **EN50160** and **IEC**.

Most respondent agree on the need for enforcing PQ requirements in future networks.

The most important PQ characteristics to be defined in future documents are harmonics, unbalance, voltage flicker, and voltage dips.

Most respondent agree on the **need for documented procedures** for setting emission limits, PQ monitoring and compliance verification.
HARMONICS

The devil is in the details ...

+ Applicable standard in each country?
HARMONICS

The devil is in the details ...

+ Applicable standard in each country?
+ Upper frequency limit? $H = 25^{th}, 40^{th}, 50^{th}, 100^{th}, \ldots$?
+ Treatment of inter-harmonics?
+ Current or voltage emission limits?
+ Fixed or case-by-case emission limits to new customers?
+ Roles and responsibilities for harmonic amplification?
+ Point of Evaluation?
+ Process for simultaneous connections?
+ Co-ordination between neighbouring countries?
ROOM FOR THOUGHT …

– Level playing field for wind/solar developers throughout Europe?

– Harmonisation of standards and PQ requirements in Grid Codes?

– Co-ordination of Power Quality between neighbouring systems?
• **D5.5** Mitigation of PQ disturbances on operation of PE rich networks.

Work started  
Publication scheduled  
December 2019
ADDED VALUE FOR STAKEHOLDERS

• Overview of existing and future PQ issues in transmission networks and identification of main sources for PQ issues

• Methodology for the assessment of the Influence of PQ Disturbance on Operation of PE Rich Power Networks is proposed

• Mitigation techniques for PQ disturbances will be proposed, techniques include device based solutions (passive and control) in order to improve the level of PQ in the transmission networks

• PQ phenomena Visualisation tool developed

• Understanding of PMU applicability for PQ monitoring
UPCOMING WORKSHOPS

• **WP1: Power System Stability Issues Under High Penetration of PE**
  • When? *October – November 2019 (TBC)*
  • Where? *TBC*

• **WP2: Real Time Monitoring and Control**
  • When? *29th October 2019*
  • Where? *Glasgow (UK)*

• **WP3: Control and Operation of a Grid with 100% Converter Based Devices**
  • When? *16th – 17th October 2019*
  • Where? *ENSAM, Lille (France)*

• **WP4: Protection Schemes in Transmission Networks with High PE Penetration**
  • When? *18th – 19th November 2019*
  • Where? *Madrid (Spain)*

• **WP5: Power Quality in Transmission Networks with High PE Penetration**
  • When? *5th November 2019*
  • Where? *Ljubljana (Slovenia)*

More details will be available in [https://www.h2020-migrate.eu/news.html](https://www.h2020-migrate.eu/news.html)
OPEN DISCUSSION
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