MIGRATE Public deliverable D1.1:

Current and arising issues caused by increasing power electronics penetration

- Synthesis and questionnaire -

Deliverable's conclusions

Deliverable 1.1 aims at identifying and prioritizing all power system stability issues brought by the increasing penetration of PE in the different control zones covered by the TSOs of the MIGRATE consortium.
To that end, a questionnaire was sent to most TSOs of ENTSO-E in order to gather their inputs regarding the stability problems they encounter, the related tools and methods they use to mitigate them and how they should evolve in the future (dynamic studies, load modelling, stability monitoring, data management, Real Time Digital Simulation), and their views on the problems not yet covered by the network codes.
This first step, coupled with a literature survey, allowed to list, in an attempt of exhaustiveness, 11 system stability issues related to PE proliferation. In a second phase, the 11 TSOs from the consortium individually assessed these issues in terms of impact on their respective network, according to three dimensions - severity, probability and timeframe of impact. The timeframe dimension leads to a lower ranking for severe problems expected not to occur within the next years.
Multiplying the mean values of the scores for the three dimensions of assessment allowed to obtain a single ranking score for each of the 11 system stability issues (scores between 0 and 3 for each dimension; theoretical maximum score: 27; theoretical minimum score: 0).

The resulting ranking is presented below:

Ranking	Score	Issue
1	17.35	Decrease of inertia
2	10.16	Resonances due to cables and Power electronics
3	9.84	Reduction of transient stability margins
4	8.91	Missing or wrong participation of PE-connected generators and loads in frequency containment
5	8.19	PE Controller interaction with each other and passive AC components
6	7.50	Loss of devices in the context of fault-ride-through capability
7	7.00	Lack of reactive power
8	6.91	Introduction of new power oscillations and/or reduced damping of existing power oscillations
9	6.09	Excess of reactive power
10	4.27	Voltage Dip-Induced Frequency Dip
11	3.87	Altered static and dynamic voltage dependence of loads

A synthetic definition of the power system stability issues is provided in the next pages. For a more complete description, please refer to D1.1 deliverable available soon at: www.h2020-migrate.eu .

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We are very interested in your feedback on this document!

We kindly ask you to answer these three questions below after your reading:

To your own view…

1. ***Are there any power system stability issues missing in the above list?***
2. ***Are there any power system stability issues that should be removed from this list?***
3. ***Are there any power system stability issues that you would rank differently?***

PLEASE ANSWER ONLINE BY FOLLOWING THIS LINK (Google Form)

For any question you can contact Clémentine COUJARD: ccoujard@technofi.eu .

Many thanks!
The MIGRATE team

Synthetic definitions of the listed power system stability issues

1. Decrease of inertia

Ranking Score: 17.35

The inertia in power systems is mainly provided by synchronous generators and the mechanically coupled turbines of conventional power plants. An increase of RES generation connected to the grid via Power Electronics (PE) implies a decoupling between the electrical and the mechanical part of the generating device, which results in a lack of inertial response to changes in grid frequency. While power system's inertia decreases, the potential imbalance incidents remains constant or increases. This leads to a higher Rate Of Change Of Frequency (ROCOF) and dynamic frequency nadirs or peaks.

2. Resonances due to cables and Power Electronics

Ranking Score: 10.16

The cables resonance and the increase of harmonic currents due to the combination of additional HVAC underground cables and the harmonic voltages emitted by PE in offshore grids change the dynamics of the grid.
The inductive behaviour of overhead power lines leads to an impedance that increases with frequency, whereas the underground cable's larger capacity results in a smaller impedance at high frequencies, causing larger harmonic currents caused by the prevalent voltage disturbances in the range of the switching frequencies, compared to overhead power lines. Larger energy storages decrease the resonance frequencies of the grid. If the resonance frequencies drop to a lower frequency range, the corresponding harmonic content may be increased or harmonic stability issues may arise.

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3. Reduction of transient stability margins

Ranking Score: 9.84

Transient stability is concerned with the ability of synchronous machines to maintain synchronism after a severe disturbance. This disturbance results in large deviations from the pre-fault operating point of the affected synchronous machines. After the fault is cleared, the synchronous machines tend to a new operating point or lose synchronism due to insufficient synchronising torque. Thus, transient stability is dependent on the fault-clearing time. The maximum fault-clearing time of a three-phase short circuit is called Critical Clearing Time (CCT) and constitutes a widespread KPI for transient stability.
Increasing PE penetration affects transient stability in various, interdepending ways, and whether the absolute impact is negative or positive depends on the superposition and interaction of these influencing factors: technology-dependent impact; penetration level-dependent impact; pre-fault operating point-dependent impact; location-dependent impact; protection-dependent impact; control system-dependent impact.
HVDC links, FACTS and PE-interfaced load influence transient stability, too. Their absolute impact on the power system's transient stability depends on active power and voltage control strategy, respectively response, technology, pre-disturbance loading, device location and fault location.

4. Missing or wrong participation of PE-connected generators and loads in frequency containment

Ranking Score: 8.91

For an effective operation of the frequency containment plans, preferably no load or generation shall trip unintentionally as long as frequency remains within the predefined band for the respective synchronous area, as it might further increase the imbalance between load and generation. On the contrary, a participation in frequency containment by providing frequency containment reserves in Limited Frequency System Mode response for Overfrequency (LFSM-O) or for Underfrequency (LFSM-U) is beneficial. Some loads traditionally participate in frequency containment by a positive dependence between frequency and power consumption. This leads to a frequency dependence of the total load: the self-regulation effect.
Network codes requirements for distributed PE-interfaced generation concerning under-or over-frequency tripping and subsequent reconnection as well as participation in frequency containment were less strict than for conventional transmission-connected generation. However, with their expansion, the absolute rated power of distributed generation became relevant for transmission system operation and led to wrong behaviour in case of frequency deviations within power classes of (several) large conventional power plants. Besides, a planned participation in over-frequency containment was planned at fixed thresholds instead of requesting a proportional reduction of power with increasing frequency. This leads to the risk of a simultaneous generation tripping which could significantly exceed the reference incident.
As grid connection of load and especially of drive systems via PE-interfaces increases, the self-regulation effect of load might decrease, because the power consumption of PE-interfaced drive systems is not frequency-dependent in general.

5. PE Controller interaction with each other and passive AC components

Ranking Score: 8.19

With the increasing share of PE devices, the number of controllers and filters within the grid rises and the share of conventional generation decreases, severely changing the grid dynamics. Newly installed PE may influence the performance of existing equipment. The ohmic-inductive model may not be sufficient to capture a high number of other PE or compensators in close electrical proximity, including their controller's dynamics and output filters. Grid dynamics within the bandwidth of the controller,

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which are not considered in the design or change over time, may impair the controller's performance and stability.
In areas with a large amount of PE generation in close electrical proximity, additional attention has to be paid to the neighbouring converter's control and output filters.

6. Loss of devices in the context of fault-ride-through capability

Ranking Score: 7.50

The network codes in some control areas do not require fault-ride-through capability for PE-interfaced generators below a certain capacity. Such fault-ride-through capabilities should limit the potential loss of generation after a fault, which affects frequency stability and causes unexpected power flows, which in turn can cause e.g. (cascading) overload line tripping, system splitting or load shedding. Therefore, a certain amount of generation still trips in case of low voltages.
Some of the interviewed TSOs expect a reduction of short-circuit power with the increase of renewable penetration, and therefore a larger propagation of voltage dips caused by short-circuit events, which exposes a greater proportion of PE-interfaced generation to an undervoltage protection trip.
In the case of wind parks, the European Wind Integration Study states that without fault-ride-through capability of such parks, the capacity of wind power that can be securely connected to the system will be considerably lower.

7. Lack of reactive power

Ranking Score: 7.00

Traditionally, voltage regulation and therefore reactive power management in the transmission grid were mainly managed with conventional power plants. Additionally, reactive power compensation devices were and are being installed by TSOs to support reactive power management, where necessary.
When PE-interfaced generation replaces synchronous generators while reaching a certain penetration level, the voltage control capabilities may be reduced within the transmission grid, as PE-interfaced generation might not provide the same voltage control capabilities.
Additionally, depending on the location of the PE-interfaced generation units and the replaced synchronous generators, the system might get higher loaded due to increased distances between load centres and PE-interfaced generation. Finally, PE-interfaced generation is often installed at distribution level, so that voltage support for the transmission system is impeded due to one or more transformer impedances.
When the grid penetration of dispersed renewable generation began, reactive power or voltage control capability was usually not required by the network codes. Hence, depending on the different dynamics of network code adjustment and renewable generation expansion, a different share of renewable generation in each control zone does not participate in voltage control. There are several measures available to mitigate a lack of reactive power in the transmission grid. The most common practice is the deployment of switchable or non-switchable shunt condensers. Synchronous condensers, tap-changing transformers and FACTS can also be used to directly or indirectly provide reactive power. Additionally, VSC HVDC converter stations can participate in voltage control. Finally, new PE-interfaced generation units compliant with current network codes and the on-going replacement of first-generation devices by modern ones can improve voltage control capabilities in the transmission grid.

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8. Introduction of new power oscillations and/or reduced damping of existing power oscillations

Ranking Score: 6.91

In a power system, the electromechanical oscillations that can occur between different interconnected synchronous machines are accompanied with fluctuations in voltage, current and power flows. Considering the frequency domain, each power system entails various modes of oscillation with different damping. Insufficient damping of one or more modes can lead to severe stability issues, e.g. (cascaded) generator or line tripping.
As of today, damping has been increased by several means: installation of PSS devices in power plants, installation of new or modification of existing FACTS, modification of existing HVDC converter stations with supplementary control, reduction of power exchange along the main direction of oscillations.
However, as the modes and their damping are dependent on the whole system configuration including all control systems, alterations of this configuration due to increasing PE penetration affect the modes and their damping by several means: affecting the modes by displacing synchronous machines; displacing PSSs by displacing the associated synchronous machines; affecting the synchronising forces by impacting the major path flows (by an altered relative position of generation and load); interactions between PE controls and the damping torque of large synchronous generators.
Also, due to the introduction of PE interfaced equipment and their control loops, new oscillation modes may arise.

9. Excess of reactive power

Ranking Score: 6.09

The reactive power demand of transmission system elements (overhead lines, cables and transformers) is highly dependable on their loading. Overhead lines require reactive power provision in case they are highly loaded and provide reactive power for low loading. Transformers always require and cables always provide reactive power, but in either case the amount depends on the current and therefore on the loading. Most of the load supplied by transmission systems is connected to the distribution systems. Hence, apart from reactive power demand of transmission system elements, the demand at the grid supply points (interface transmission/distribution grid) has to be balanced by generators or reactive power compensation.
In case the reactive power demand of distribution systems at the grid supply points reduces or gets negative during times of low load, reactive power has to be consumed by generators or compensation devices. As this capability is limited, the voltage rises above the permissible voltage band in case of excessive reactive power. As increasing PE-interfaced generation penetration can reduce the voltage control capabilities of transmission grids, this might aggravate the issue, especially because the relative share of PE-interfaced generation (in particular wind generation) can get higher in times of low load than of high load.

10. Voltage Dip-Induced Frequency Dip

Ranking Score: 4.27

This issue refers to the recovery phase of active power after short-circuit events. The active power recovery of transient stable synchronous generators follows the recovering voltage and is therefore very quick. The active power recovery of wind turbine generators may be slower in order to keep mechanical stress on the structure at acceptable levels. The impact of this issue is strongly dependent on the size of the synchronous area together with its inertia and the wind power penetration. The issue is aggravated by decreasing inertia and a broader propagation of voltage dips. PE-interfaced generation without a mechanical prime mover, such as photovoltaics, can be controlled in such a way that they do not significantly contribute to this problem.

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11. Altered static and dynamic voltage dependence of loads

Ranking Score: 3.87

The voltage dependence of loads can be distinguished with respect to the behaviour during the time after a voltage variation. If the alteration of active and/or reactive power consumption caused by a varied voltage is permanent, the load is denoted static. In case the power consumption changes with time without a further voltage variation, the load is denoted dynamic. Typically, dynamic loads restore power consumption completely or to a certain extent. Depending on its controls, a PE-interfaced load can either be static or dynamic.

As load behaviour is a main factor influencing voltage stability, alterations in both static and dynamic voltage dependence have an effect. Due to the complexity of current power systems with its numerous highly nonlinear relations, the effects depend on several factors and can only be evaluated in detail by studies on the concrete system.

Besides voltage stability, frequency stability is also affected by the voltage dependence of load. As the loss of generation or an importing HVDC link is often accompanied by voltage drops, voltage dependence of load has a stabilising effect on frequency, because the loads affected by decreasing voltages reduce power consumption. Depending on the power system, its specific configuration and also the type and location of a fault, the positive effect of voltage dependence of load can largely exceed the effect of frequency dependence.

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