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MICROGRID STABILITY: A REVIEW ON VOLTAGE AND FREQUENCY STABILITY

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Content

Introduction

- Distribution networks face the challenge of optimum and cost-effective operation. In order to fulfil these requirements, a concept of advanced and intelligent network is introduced.

- Smart grid allows consumers involvement in consumption planning and monitoring, as well as integrating DG into the grid.

- MG operation: islanded mode or in the on-grid mode.

- Grid control methods depend on operational mode; operational management requirements are the same as for the conventional network operation [1].

Introduction

- Basic requirements: active power balance, respecting nominal loading limits of network elements, maintaining system reliability, minimising voltage deviations and fulfilling power quality indicators.

- During the grid-connected mode, MG supplies the external network with the reactive power, while the voltage and frequency are determined by the external grid.

- If the DG production is decreased, an external grid compensates the lack of the active power and there is no voltage deviation in MG.

- Any fluctuation of DG electricity generation in the islanded operational mode can cause voltage variation in MG.

Introduction

- When islanding of the MG occurs, role of system voltage and frequency regulation is switched to the DG that adjusts its control modes and power dispatch.

- Transient system responses of the MG are slower in comparison with the on-grid operational mode, while the dynamic response and the steady state is achieved much faster.

Types of MG

- Based on DG sources types, MGs can operate as DC, AC or hybrid.

- DC DG sources have the advantages when suppling loads sensitive to voltage variations.

- Hybrid MGs consist of both DC and AC sources and equipment connected to the inverters combining the advantages of both AC and DC systems. In order to keep these grids operational, constraints for AC and DC types of grids have to be satisfied (currents, voltages, temperatures, etc.).

2. GRID STABILITY CLASSIFICATION

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- Power system stability is defined as system's ability, for a given initial operating conditions to regain a steady state of equilibrium after being subjected to a disturbance.

- Power system stability is classified into three basic types: voltage, frequency and small-signal stability; for a large and small disturbances and both long-term and short-term disturbances.

- MG stability is classified by the same criteria with the exception of classification regarding the part of the observed system – Stability of the Control System or the Power Supply and Balance Stability.

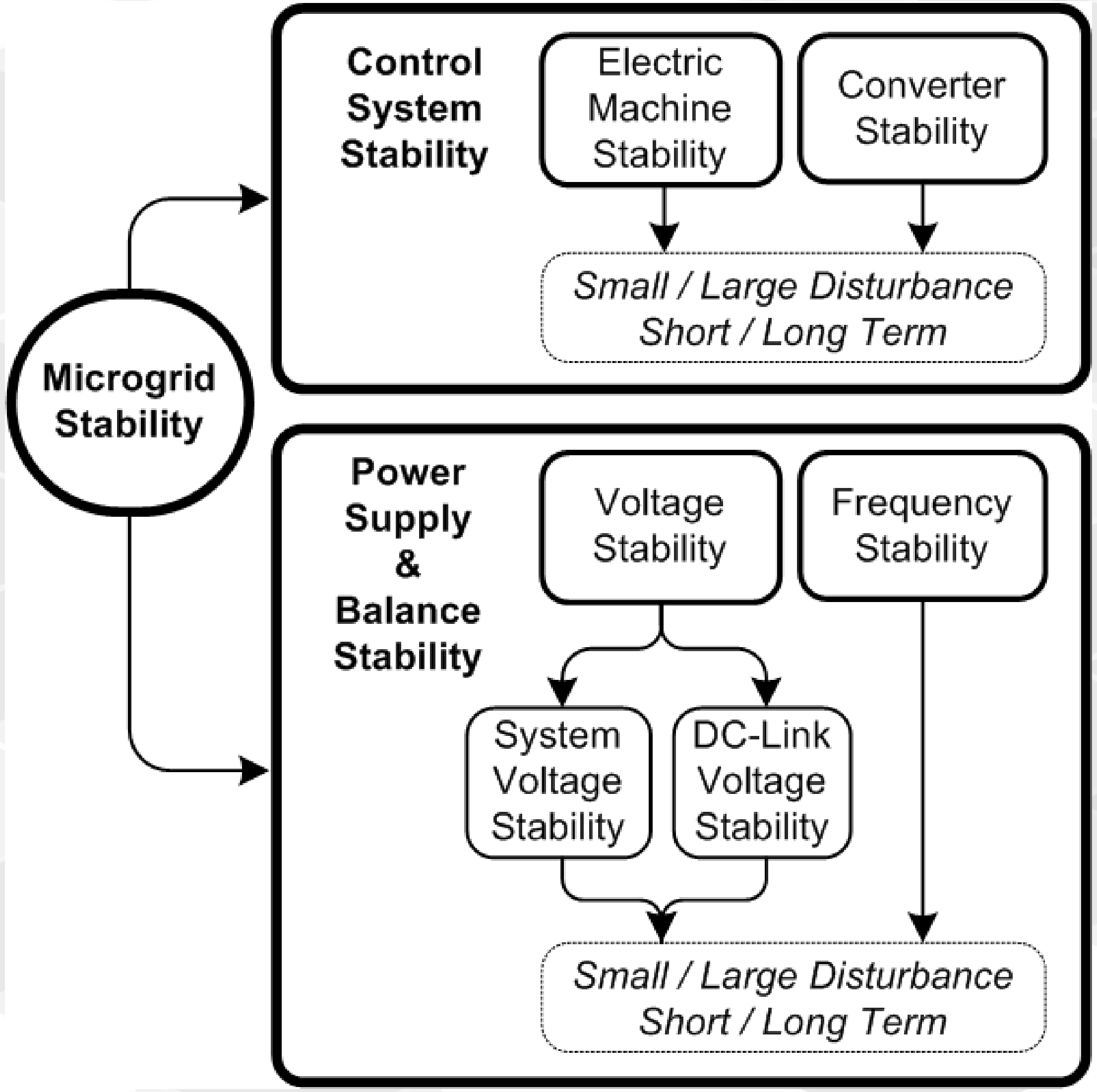

Fig. 1 MG Stability Classification

Stability of the Control system

- Stability of the Control system refers to electrical machine and converter stability.

- Control system instability occurs due to inadequate operational parameters tuning (electrical machine with inadequate tuning of exciting system or voltage regulator, insufficient synchronization moment).

- Converter instability occurs due to inadequate converter selection or as in previous case, due to improper converter tuning which can also result in generation of the high order harmonics.

Power Supply and Balance Stability

- Power Supply and Balance Stability is system ability of keeping active power balance.

- Control System stability is analysed through two aspects as voltage and frequency stability.

- Due to stochastic nature of renewable energy sources (RES) and low inertia, even small active power deviation can cause significant frequency deviation.

Voltage stability

- ► Voltage stability refers to general system stability and DC – Link Capacitor Voltage Stability.
- ► DC – Link Capacitor can be used for inertia emulation and system dynamics improvement by creating additional energy storage to eliminate voltage deviations and dips -> any voltage change leads to reactive power fluctuations which can affect the complete grid.
- ► Starting point for voltage stability analysis is the bus classification with three basic bus types: Slack Bus, PV Bus and PQ Bus.
- ► On the other hand, inverter-based distributed energy sources (DER) due to the limited DG dispatch and stochastic changes depending on external influences, cannot be considered as PQ bus nor Slack Bus.

MG specifics

- Since specific MG configuration (DG, short feeders, different X/R ratios, unbalanced loads, low inertia), stability requirements differ from the conventional grids.
- Since the lines can appear inductive in transmission lines or resistive in smaller lines a clear link between active power and frequency (i.e. voltage and reactive power) control cannot be defined.
- In MGs, a coupling between active power and voltage control is more noticeable than connection between voltage and reactive power control as it would be expected.
- Although feeders are shorter, if there are significant numbers of consumers connected along feeders or loads on considerable distance, it is impossible to control voltage on the Point of Common Coupling (PCC). In such case, a combination of control methods using grid converters and DGs is used.

- In order to decouple power, and thus their influences on voltage levels, a parallel LC filter can be introduced.
- LC filter, which is used to add virtual impedance, reduces voltage and current ripples giving desired impedance output and improving system damping. Poorly tuned filter can be new source of system instability.
- A Linear – Quadratic Regulator (LQR) can be combined with converter and LC filter. Regulator is implemented in Voltage Source Converter (VSC) and ensures better system control and faster transient response.
- Changing inductance and capacity parameters, a wide range of regulator application can be achieved which shows regulator robustness. This type of regulator can be used in any MG configuration even if some main loop parameter are unknown.

LC filters and virtual impedance

- Virtual impedance introduced by filters and additional control elements allows easier voltage and frequency control.
- Poor network management can lead to instability, so optimal control parameters has to be achieved; optimization methods are mainly carried out by some type of soft computing method.
- *PV* and *QV* curves can also be used for voltage control as they are useful for unbalanced system analysis.

Frequency Stability

- Frequency control is associated with system inertia constant.
- Conventional power systems consist of large synchronous generators with large masses which can accumulate enough kinetic energy to maintain system stability in conditions of large and small disturbances.
- Inverter-based DER (e.g. photovoltaic, wind generator), or fuel cells cannot give inertial response so additional inertia must be emulated with inverters and energy storages systems (ESS).
- ESS accumulate energy in variate forms, e.g. kinetic (flywheels), chemical (various types of batteries), potential (pumped – storage hydro power plant), Vehicle- to- grid concept or by adjusting operating points in order to keep RES generation under its maximum output power.

Frequency Stability

- If active power generation varies, ESS supply energy into the grid, and thereby decrease oscillations which occur during load fluctuations.
- Another solution is vehicle to grid concept which is activated if frequency deviations cannot be eliminated, while the system control is realize using fuzzy logic which is simpler and more adjustable control system than PI regulation.

Virtual Synchronous Generator or Energy Storage?

- All above mentioned methods use virtual inertia emulation or ESS.
- Main disadvantage of wider use of ESS are large investment and limited capacity.
- The most commonly used ESSs type are batteries which support grid during the switching transients and load shedding.
- Selection of an adequate battery type depends on the response speed criteria or response quality criteria.
- Alternative to physical ESS are artificial inverter-based storages. All inverter-based RES generation provide less inertia and damping torque than synchronous machines, therefore inertia has to be emulated.

Virtual Synchronous Generator or Energy Storage?

- Alternative to physical ESS are artificial inverter-based storages. All inverter-based RES generation provide less inertia and damping torque than synchronous machines, therefore inertia has to be emulated.
- Virtual synchronous generators (VSG) behave like conventional synchronous generator (SG) in the steady-state.
- During the transients, they react on frequency fluctuations in real time since the inertia emulation is based on the mismatch between the values of momentary system frequency and the VSG reference.
- Transients are shorter and in some cases they even do not occur.
- Benefits of VSG are especially noticeable if used in combination with ESS. During the primary control, the energy stored in ESS is used to decrease frequency fluctuations[43].
- Regarding to *P-V* or *P-ω* control loops, VSG behaves better in transient conditions] but on the other hand, the output power has larger oscillations.

Virtual Synchronous Generator or Energy Storage?

- There are two types of output voltage control: voltage controlled source (VSI) or current controlled source (*P*/*Q*).
- In the islanded mode of operation VSI forms the voltage and the frequency values the same as defined by external grid.
- These types of inverters are also commonly referred as "grid – forming" inverter.
- Frequency of the MG is defined by inverter output power which allows power sharing among parallel-connected inverters (shared power depends on particular inverter power).

Grid –feeding inverter

- Second type of voltage control in inverter are current controlled voltage source commonly referred as *PQ – grid – feeding inverter, with* ability of parallel work with the power source which gives frequency reference for converter control.
- *PQ* injects the power (both active and reactive) in system and usually works in combination with grid – forming inverter. Output power is predefined while the deviations are corrected using PI regulators.
- Both converter types are suitable for MG although VSI has better characteristics because it can withstand slight overvoltage and they can withstand a short-time overload. Grid – forming mode has the advantage of faster elimination of frequency deviations due to possibility of emulation of higher inertia levels.

Hierarchical control in MG

- Conventional power system consists of three hierarchical control levels: primary, secondary and tertiary.
- Primary control keeps the frequency in permitted levels and is realized directly at the DG.
- This control level is based on tracking active power generation and consumption.
- If the generation exceeds the consumption, the frequency will increase and vice versa; the rate of change of frequency (ROCOF) will indicate an unbalance in the system.
- The ROCOF is indicator is also used as one of the methods to supervise system protection.

Secondary control

- ► Secondary control level is slower than primary, and it is used to return operating point in optimal position after primary control is done and usually it is realized on the Microgrid Central Controller (MGCC).
- ► In order to have fast and complete secondary control, the communication channels are desirable.
- ► This control type can be realized as centralized, decentralized od distributed, depending on which type of communication channels are used or if there are regulators with communication ability.
- ► Communication is organized as mutual or hierarchical
- ► Various alghorithms are used to implement communication (nodes, cyber-physical chanells,...)

Tertiary control level

- Tertiary control level is used to find optimal dispatch and this is the slowest control level which is realized on the energy exchange level. Exchange is realized between MG and the external grid.
- Complexity of the models used for stability analysis depends on expected accuracy level.
- Primary control droop is usually represented with linearized model which guarantees local stability; all nonlinear dynamic processes and unknown impedance values are neglected.

Hierarchical control application

- Primary control is always implemented using droop control while secondary control depends on converter type.
- Both converter types are equipped with control circuits with PI regulators.
- VSI is implemented with double secondary loop where the inner loop is used to keep system stability while the outer loop is used to ensure the reference voltage level.
- *P/Q* also uses double PI regulator droops to keep output current as reference. Communication between nodes is multi-agent; mutual system communication leads to faster deviation elimination and return in stable steady-state.
- PI regulator parameters are predefined or adopted to system in real-time and their parameters are adjusted using artificial neural networks or fuzzy logic.

Control loops

- Voltage regulation is implemented using droop or VSG.
- Control loop is usually used to regulate the voltage and the frequency and to control the active and reactive power flows of the converter.
- Low voltage control loops can also be adjusted to compensate feeder impedance while keeping in mind that overcompensated feeder impedance can become a new source of system instability.
- A combined voltage control method: grid – forming and grid – feeding VSG emulate inertia which decreases voltage surge and improves system inertial and transient response but the output frequency can be reduced and the output power can oscillate.
- This method can be applied on MG with integrated ESS despite its deficiencies.

Conclusion

- MG control is complex task due to specifies that define MG, like different grid character in comparison to conventional grids.
- Feeders are shorter and loads are unbalanced. Stability is analysed from voltage and frequency stability aspects.
- In grid-connected mode, voltage and frequency control is not as demanding as in islanded mode with DG forming the grid in accordance with consumer constraints.
- This paper gives an overview of the most common voltage and frequency stability analysis methods, most commonly used configurations and overview of hierarchical control methods found in the literature.
- It is crucial to notice that all above mentioned methods are realized with soft computing methods which take important role in grid assessment and management.