STANDARD DESIGN OF E-STATCOM OF THE GERMAN TSO

Integration of E-STATCOM into the German transmission grid

In December 2020, the 4 TSOs described the need for grid-forming STATCOM plants in [1]. A distinction was made between phase 1 to provide dynamic reactive power and phase 2 to provide dynamic reactive power and inertial response. For grid-forming STATCOM of phase 2, a power electronics based dynamic reactive power compensation system from the group of FACTS, the term Energy STATCOM (E-STATCOM) is used in literature e.g. in [2]. The additional integration of a short-term energy storage enables E-STATCOM to compensate for short-term load fluctuations and thus to provide the grid with inertial response in addition to dynamic reactive power.

In addition to the short-term energy storage, grid-forming control of the STATCOM is a necessary prerequisite for an E-STATCOM to provide dynamic reactive power and inertial response. In [3] an example of a phase 1 grid-forming STATCOM is described, in [4] and [5] basic characteristics of grid-forming equipment are described.

The BNetzA has confirmed a large number of E-STATCOM in [6]. In the following, the 4 German transmission system operators have started implementation.

Due to the large number of plants and because of the high time pressure caused by the energy transition, the transmission system operators want to make the construction of the plants as fast and efficient as possible. One measure for high efficiency is standardisation. In principle, standardization is always a trade-off between an efficiency gain through standardization of many plants and an efficiency loss, since each individual plant can no longer be optimally adapted to the specific conditions. Due to the spatial and technical conditions, complete standardization of the plants is therefore not possible, but the transmission system operators aim to achieve the highest possible degree of standardization.

Standard of German 4 TSO

Taking into account the technical conditions in the network, the most important key ratings of the E-STATCOM plants were identified and uniform values for these key ratings were defined for future projects in Germany.

Power ratings

Table 1 shows the defined standard rating.

Table 1: Standard ratings for E-STATCOM of the German 4 TSO

S_{Nom} /. S_{Max}	level of simultaneous provision (minimum requirement)		storage in MWs @P_2	$RoCoF_2$ in Hz/s	P_1 in MW @ 1Hz/s	P_2 in MW @2 Hz/s	Q_n in Mvar	$T_{A,P}$ in s	Inertia contri-bution in GWs
	P_{sp} in MW	Q_{sp} in Mvar							
300	75	290	375*	2	75	150	300	50 relative to 75 MW	1,875

*For operation within the frequency limits 47,5 Hz to 52,5 Hz

- S_{Nom} / S_{max}:
  Maximum apparent power for which the plant with its components is designed.
- level of simultaneous provision:
  Due to the converter topology, typically the maximum active power and the maximum reactive power cannot be delivered simultaneously, the power capacity is dependent on each other, the P-Q diagram of the system is circular or elliptical. However, for the stabilising effect of the E-STATCOM plants, it is necessary that active and reactive power are provided simultaneously. Therefore, it must be defined up to which limit this must be possible as minimum requirement.
  - P_{sp} in MW:
    Active power that must be supplied simultaneously with the reactive power Q_g.
  - Q_{sp} in Mvar:
    Reactive power that must be supplied simultaneously with the active power P_g.
- storage in MWs @ P_2:
  The storage size is defined uniformly. Since in some topologies the usable energy content of the short-term energy storage depends on the discharge or charge power due to the internal resistance of the short-term energy storage, the storage size is defined for a specific charge/discharge power. It is understood as energy that can be made available to the AC grid.
- RoCoF_2:
  Rate of change of frequency (RoCoF) for the maximum inertial active power contribution of the E-STATCOM system.
- P_1:
  Inertial active power contribution for a frequency change of 1 Hz/s according to the design limit of the implemented system protection plan of the continental European synchronous zone.

- P_2:
  Inertial active power contribution for a frequency change $\dot{f}_2$ of 2 Hz/s, for locally higher frequency change above the design limit. Maximum possible active power.
  The energy content of the storage and the maximum active power contribution P_2 result in the maximum period of supply of active power at ${}^{375\ MWs}/_{150\ MW} = 2{,}5\ s$. With an resting state of charge of 50% at 50 Hz, this results in a charge/discharge duration at 2 Hz/s of 1.25 s until 47,5Hz or 52,5 Hz is reached.
- Q_n in Mvar:
  Nominal value oft he reactive power. The maximum continuous reactive power Q_max.is defined to the same value.
- $T_\mathrm{A,P}$ in s:
  The planned configuration for the acceleration time constant by which the inertial response is defined. The acceleration time constant $T_\mathrm{A,P}$ relates to the inertia time constant H as $T_\mathrm{A,P} = 2 \times H$
- Inertia contribution in GWs:
  Inertia contribution resulting from the acceleration time constant and the reference power. P_1 is defined as reference power. The inertia contribution results to $Inertia\ contribution = \frac{1}{2} \cdot T_\mathrm{AN} \cdot P_1$.
  This inertia contribution is the contribution of each E-STATCOM plant to the total inertia contribution that according to [6] shall be provided by the German transmission system.

The power is to be provided over the respective defined voltage range for quasi-stationary operation.

Voltage range for quasi-stationary operation

The following specifications are defined for the voltage range.

Design points for under voltage:

1. Overexcited/capacitive 300 MVar down to 360 kV, below that down to 340 kV according to current capability, below that according to Under Voltage Ride Through (UVRT) characteristic.
2. Underexcited/inductive 300 MVar down to 380 kV, below that down to 340 kV according to current capability or other system restrictions.

Design points for over voltage:

3. Underexcited/inductive 300 MVar up to 440 kV, above that Over Voltage Ride Through (OVRT) characteristic curve.

4. Overexcited/capacitive 300 MVar up to 420 kV, above that up to 440 kV according to voltage limits or other system restrictions.

Depending on the current carrying capacity and other system restrictions, this results in a Q-U diagram that contains at least the design points mentioned, but does not necessarily connect these design points with straight lines, but describes the largest possible operating range according to the system capacity. Figure 1 shows an exemplary Q-U diagram.

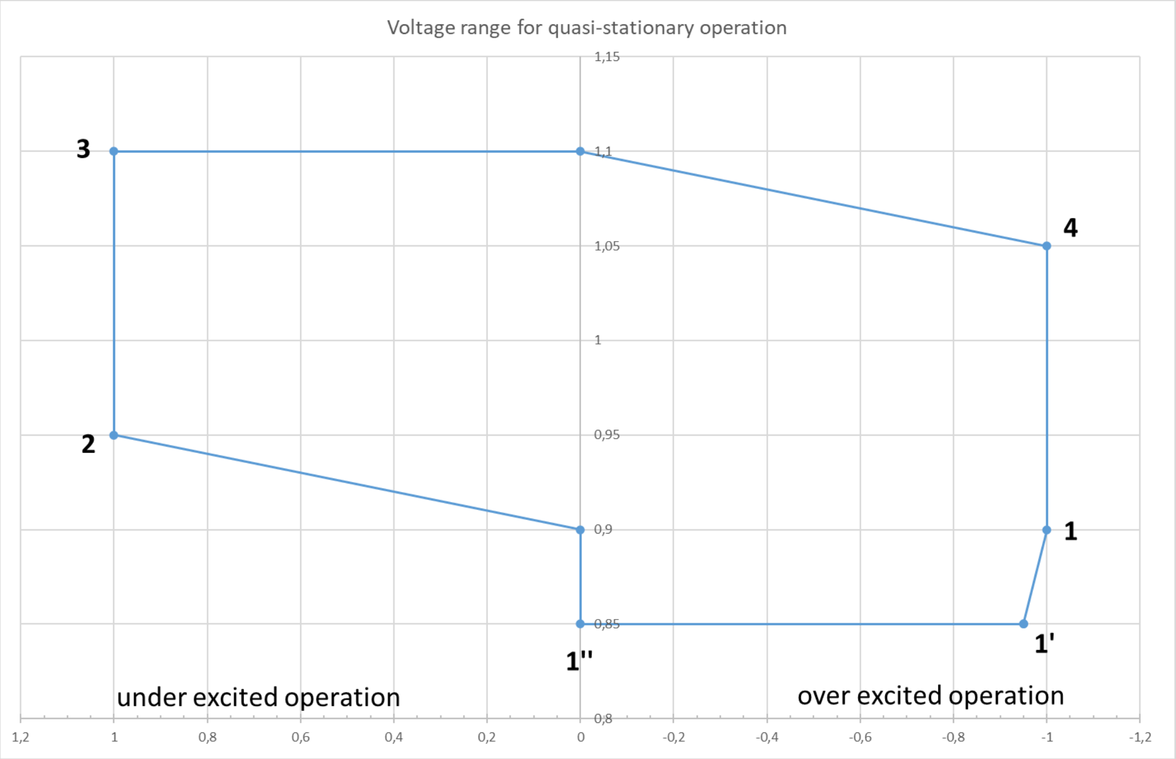

Figure 1 Exemplary Q-U diagram (consumer reference frame)

Further definitions

The short-term energy storage system must be designed for a service life of at least 20 years.

The availability of the E-STATCOM must be as already specified by the German TSOs for STATCOM systems.

Implementation

The 4 German TSOs aim to apply the standard ratings to all new projects as soon as possible. Since the plants go through a large number of planning phases before construction begins, starting with the network development plan and extending many years into the future, it must be checked in each individual case which plants can be changed to the standard ratings. An adjustment is not to be expected for plants that are already contracted.

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