Mission
The entire energy system is currently at the beginning of a complete and fundamental transformation: away from fossil fuels (and in some countries also from nuclear fuels) towards new renewable energy sources. This transformation is driven by the desire to make clean energy available and affordable for everyone and is typically considered one of the most important challenges humanity currently faces. The role of electric energy will be central in the future energy system. High voltage engineering is essential for the transmission technology as, on the one hand, power is transmitted preferably at the highest possible voltage levels, but on the other hand, the available space for substation equipment is decreasing, in particular on off-shore platforms.

The research and teaching focus of the High Voltage Laboratory is in the area of "technologies for future electric power transmission systems". The two focus areas are: 1. High voltage Direct-Current Transmission (HVDC) Technology and 2. High voltage Gaseous Insulation Systems. Our project topics are the search for insulation gas mixtures alternatives to SF6, HVDC insulation systems, hybrid AC-DC overhead power lines, simulation of transient short-circuit currents in multi-terminal HVDC networks, and experimental studies to characterize and optimize switching arcs for HVDC circuit breakers.

By systematically introducing the latest experimental and numerical methods, we advance the research in the classical area of high voltage engineering; an area where some of the research questions have a long history of investigation but are still not answered completely satisfying. The driver for our research is to use conceptually different research approaches in the projects. This differentiates us from others working in similar areas of research and enables us not only to solve the investigated problems but also to gain a basic physical understanding of the involved processes. The research is done mainly experimentally, backed by multi-physics simulations that partially contain newly developed models.
Research Activities and Achievements

HVDC Transmission Technology

HVDC systems are envisaged to play a key role in the future electric power transmission system. Traditionally, HVDC was primarily used for very long overhead power line or cable connections, for asynchronous interconnections, even connecting systems with different power frequencies. New developments in power semiconductor devices and converter technologies, in particular by the introduction of large power Voltage Source Converter (VSC) links. One of the main open questions towards HVDC grids concerns the fault handling on the DC side. Blocking the IGBTs in VSC systems is not sufficient to create current zero and to interrupt DC currents. With these, several technologies have been proposed to build DC switchgear ranging from pure semiconductor based devices to pure metal contact devices operated with mechanical drives. As no operational experience exists and as these new applications are only envisaged and not fully planned, the requirement specifications are also unclear.

HVDC network protection is still at a very early development stage and dominated by the conflicting results of studies done separately by power systems or high voltage equipment specialists. The current research of the group is characterized by a two-fold approach comprising both aspects: a) derivation of the requirement specifications for HVDC switchgear, we perform simulations and calculations of the transient system current under fault and normal operating conditions. b) development of optimized and improved switchgear; we perform basic research of switching principles with particular focus on arc based solutions.

Task a) is mainly done by transient simulations of surge propagation in cable and overhead line multi-terminal HVDC networks (see Figure). Analytic approximations serve as the basis for standardization work of simple estimates in rate-of-rise and amplitude of fault-current levels. Task b) connects to decades of very successful AC switchgear developments. The focus is on arc based HVDC switching technologies. Core innovation of our work is a conceptually new approach of switching arc characterization. Classically, mere or less systematic tests have been made varying the passive external components of DC switchgear. Changes in the arc chamber have not been addressed or were based on AC test currents. The arc has then been characterized by using complex evaluation methods applied to numerous measurements with varying sinusoidal current amplitude and current gradients.

Our conceptually novel approach here is to radically simplify the evaluation method but to use complex test currents. The idea is based on the physical understanding of an arc that can be characterized typically by a steady-state and a transient time. Sinusoidal currents have quasi-steady-state only at the maximum and minimum value and the steepest gradients. Strictly speaking, sinusoidal currents are unsuitable for characterizing arcs, and it is only possible to derive at least some information with sophisticated evaluation routines. The ideal test current would be a step current with increasing or decreasing amplitude and sharp transitions.

We have analyzed this new testing idea theoretically with promising results. We have then designed, constructed and set-up a novel test current source which can deliver arbitrary test currents up to 3 kV, 3 kA, and 150 kA (ms) at 1 kHz (see Figure). With it, we have achieved arc characterization with unprecedented accuracy and we have characterized switching arcs in an extremely wide range of different arc chamber modifications. From it, we have shown that it is possible to substantially decrease the footprint of a metal-return transfer breaker for HVDC application without any performance reduction, only by using an improved arc chamber design that results in an optimal arc characteristic.

Gaseous Dielectrics

Generally speaking, the area of Gaseous Electronics deals with the interaction of electrons and photons with atoms and molecules in their ground and excited states and with ions. Gaseous Dielectrics describe the processes relevant for a breakdown of a gas, i.e., the transition from its insulating to a conducting state. Gas insulation has a broad use in electric power systems and SF$_6$ is considered the single best medium for HV GIS applications. But as its Global Warming Potential (GWP) is ~25'000 times higher than that of CO$_2$, alternative insulating gases are searched for.

In High Voltage Engineering this area is classically studied by measuring the electric withstand or breakdown strength. This has been predominantly done by performing and evaluating breakdown tests. A large number of breakdown experiments have to be carried out to properly account for the statistical nature of the breakdown process and it has to be ensured that each measurement is independent of the previous ones. The resulting information is only valid for the chosen electrode configuration and wave shape and cannot be generalized or otherwise transferred. Thus, the electrical insulation design techniques should rather be based on the understanding of discharge mechanisms.

In the last four years, the high voltage research group has developed a novel unique and systematic approach of searching for SF$_6$ alternatives. Our new approach follows a three step procedure: i) a systematic and efficient pre-screening method to identify a small number of molecules (as the electron attaching gas within mixtures) with high electric strength, low boiling point and low GWP, ii) an efficient method to quantify the interaction of these molecules with buffer gases, and iii) to quantify the electric strength (or breakdown voltage) of the gas mixture for all technical relevant geometrical conditions and voltage wave shapes. The pre-screening method is based on empirically found predictor functions that are constructed from molecular properties (like polarizability, dipole moment, etc.) which can be computationally calculated by means of quantum-chemical methods. [Franck, OIP 2014]

Instead of quantifying the electric strength of gases and gas mixtures by performing solely breakdown measurements, we approach the question from a macroscopic understanding point-of-view. We use an experimental swarm method, the pulsed Townsend (PT) method, to provide measurements of the electric breakdown strength.

Finally, the measured macroscopic parameters of novel gases and gas mixtures have to be related to the breakdown strength in technical relevant geometries. To do so, we investigate and further develop models that calculate the process of transition from streamer to leader discharges. Important parameters are only the external electrode geometry and electric field parameters, some thermodynamic gas parameters, and the measured swarm parameters.

All three individual steps are completely established and have been validated individually. We are currently pursuing for the first time to follow the complete procedure for a single gas.