# 1 Introduction

Coil Innovation specialises in the design, manufacture and sales of air-core dry-type reactors for electric power transmission and distribution systems.

Coil Innovation is a private limited company (GmbH) and run by a team with a wealth of experience in this branch of business and a high degree of product knowledge. For the manufacture of power inductors, modern production facilities were built in Eferding, in the heart of Upper-Austria, consisting of approximately 5000 m² of production area and 1000 m² of office area.

Innovation and quality are the key elements of the strategic alignment of Coil Innovation. Many clients, having visited the ultra-modern reactor production facilities in Eferding, were able to convince themselves of the high level of innovation and quality in design and production of air-core dry-type reactors and already attest Coil Innovation the technological market leadership.

Coil Innovation succeeded to successfully enter all major air-core reactor application segments for markets around the world and has already supplied air-core reactors to destinations on all continents for the electric power industry as well as to electric utilities.

Major utilities are already employing Coil Innovation reactors in their transmission systems, just to mention some of them: Verbund-APG (Austria), E.ON (Germany), EnBW (Germany), N-ERGIE (Germany), RTE (France), Statnett (Norway), Fingrid (Finland), Tennet (Netherlands), REN (Portugal), SEC (Saudi Arabia), Duke Energy (USA), Pacific Gas & Electric (USA), LFC (Mexico), CFE (Mexico), Transelec (Chile), Western Power (Australia), ESKOM (South Africa).

The purpose of this document is to describe the design and construction of Coil Innovation's air-core dry-type reactors as well as their type designations and their range of feasible ratings. The paper will further discuss the different reactor applications.

# 2 Air-core dry-type reactors in general

Air-core dry-type reactors are mainly employed in electric power transmission and distribution systems as well as in electric power systems of electrical plants. They are installed to protect these systems and to increase their efficiency. Another, more special application of air-core dry-type reactors is the use in electrical test laboratories or research institutions.

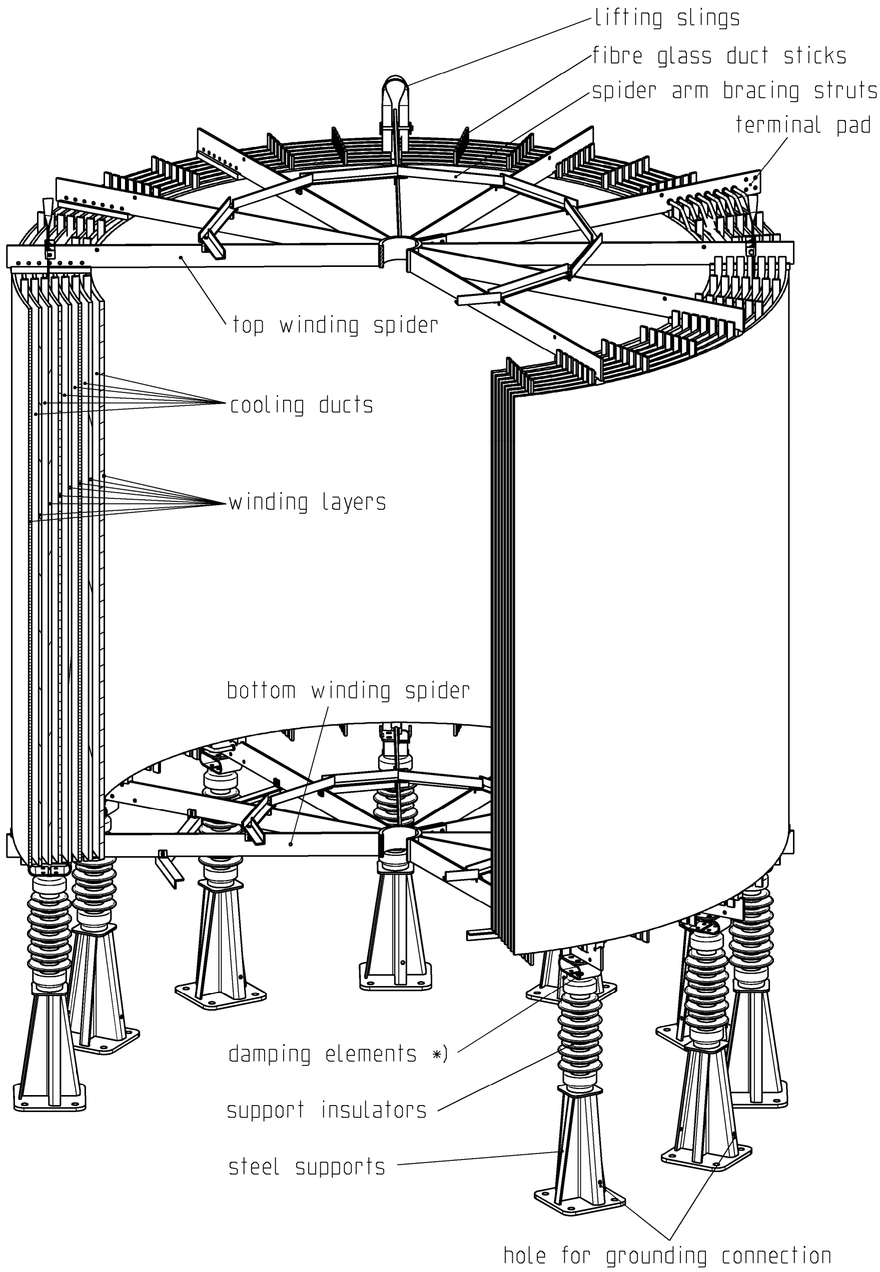
With the ongoing development of electrical power technology, especially through the increased use of semiconductors in electric power systems, the requirements of power inductors have changed during the last decades. The application spectrum for air-core dry-type reactors has been extended, caused by economic and technical advantages of the air-core reactor technology in comparison with iron-core reactors (dry-type and oil-immersed).

The utilization of new weatherproof insulation materials and advanced manufacturing technologies has facilitated the use of air-core dry-type reactors up to the highest voltage and power levels.

Air-core dry-type reactors do not utilize an oil insulation system. They are environmentally-friendly and there are no fire hazard concerns. Furthermore, air-core dry-type reactors are essentially maintenance-free.

# 3 Design and construction of air-core dry-type reactors

Below drawing only shows the principle layout of an air-core dry-type reactor manufactured at Coil Innovation, in order to explain the technical terms. The design and construction of reactors supplied for a specific contract may not necessarily look identical.




*) for heavy coils only

Principle layout of a Coil Innovation air-core reactor

Air-core reactor windings are either made of one single layer or consist of several concentrically arranged, electrically parallel connected layers. For economic reasons air-core dry-type reactors are generally made of aluminium conductor material. Either rectangular shaped aluminium cables or solid conductors are employed, which are insulated with high performance film insulation and woven tapes made of glass and polyester fibres.

The winding layers are radially spaced from each other by fibre-glass sticks, which provide the vertical ducts for natural convective air-cooling of the winding. The fibre glass reinforced duct sticks are further used to clamp the winding between metallic structures attached to the ends of the winding, the winding spider arms or the winding end beams.

Windings comprising of only one layer do not have any duct sticks and are therefore clamped together by means of impregnated glass fibre ties attached along the outer surface winding. Between the winding spiders and the active part of the winding fibre-glass end spacers are affixed.

The mechanical strength of the winding is achieved through the impregnation with a thermo set heat curing epoxy resin, which exhibits superior electrical properties and high resistance against weathering. Finally all surface areas of the winding, which are exposed to sunlight, are coated with a UV-protective paint.

Some installations are located in areas subjected to heavy industrial or oceanic based pollution. On reactor windings with high continuous surface voltage an additional protective silicone coating is applied for such adverse operating environments to eliminate the risk of surface tracking. The silicone coat has hydrophobic properties and prevents water filming on the winding surface.

Air-core dry-type reactors are mounted on a structure consisting of a number of aluminium or steel supports and support insulators. The aluminium or steel supports are suitable for direct mounting on the concrete foundation.

Large air-core reactors and reactors designed for high voltages or short-circuit currents are commonly made as single phase reactors. The three phases are arranged side-by-side. For moderate power and voltage ratings the three phase reactors may be stacked.

# 4 Range of technical data of Coil Innovation air-core dry-type reactors

The table below shows the range of technical data, which can be designed, manufactured and tested at Coil Innovation.

A major parameter describing the physical size of an air-core dry-type reactor is the reactive power. To use this parameter for AC and DC application the table below refers to the ***equivalent reactive power at rated power system frequency*** (either 50 Hz → $S_{50\,Hz}$ or 60 Hz → $S_{60\,Hz}$), which may be calculated as follows:

$$S_{50Hz} = I^2 \cdot 2\pi \cdot 50 \cdot L \qquad S_{60Hz} = I^2 \cdot 2\pi \cdot 60 \cdot L$$

$S_{50\,Hz}$ 50 Hz-equivalent reactive power $S_{50\,Hz}$ in [VAr]
$S_{60\,Hz}$ 60 Hz-equivalent reactive power $S_{60\,Hz}$ in [VAr]
I Rated continuous DC current or rated continuous AC current (r.m.s.) in [A]
L Rated inductance in H

| Reactor parameter | Range of technical data |
|---|---|
| Max. system voltages:<br>• DC systems<br>• AC systems | <br>Low voltage up to 800 kV<br>Low voltage up to 500 kV<br>*(up to 800 kV if LIWL ≤ 1700 kV)* |
| Max. continuous voltage across the reactor | 145 kV, r.m.s. |
| Max. lightning impulse withstand level (LIWL) | 1700 kV |
| Rated continuous current | 100 A up to 10 kA |
| Rated inductance | 10 µH up to 1,5 H |
| Power ratings (50 Hz-equivalent reactive power $S_{50\ Hz}$*):<br>• for DC reactors<br>• for AC reactors | <br>50 kVAr bis 250 MVAr<br>50 kVAr bis 85 MVAr |
| Power ratings (60 Hz-equivalent reactive power $S_{60\ Hz}$*):<br>• for DC reactors<br>• for AC reactors | <br>60 kVAr bis 300 MVAr<br>60 kVAr bis 102 MVAr |
| Max. physical winding dimensions:<br>• winding outside diameter<br>• winding height/length (excl. supports and insulators) | <br>up to 4 m<br>up to 4 m |
| Max. winding mass (excl. supports and insulators) | up to 30 to |
| Ambient temperatures | -45°C up to +50°C |

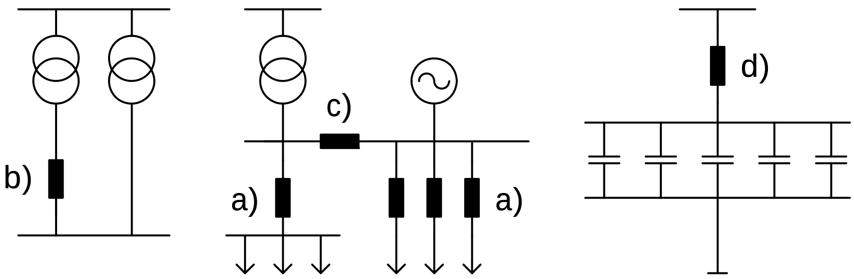
# 5 Air-core dry-type reactor applications

## 5.1 Current limiting reactors

Current limiting reactors (a) are series connected to the transmission/distribution line or to the feeder in order to limit the short-circuit power on the load side of the reactor. The reactor limits the short-circuit current to a level which can be handled by the components installed in the electrical system, such as breakers, switches or fuses. Due to the linear inductance-characteristics over the current range the full reactor impedance is also maintained during system fault conditions.

Other special applications of current limiting reactors are:

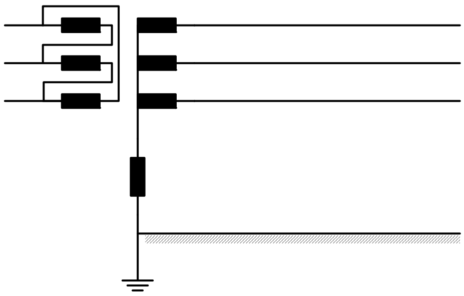
- Load balancing reactors (b) for load sharing in parallel circuits
- Bus tie reactors (c) installed between two different bus systems
- Capacitor inrush current limiting or damping reactors (d)




*Current limiting reactors*

## 5.2 Neutral grounding reactors

Neutral grounding reactors are used for low-impedance grounding of the neutral point of three-phase networks in order to limit the fault current in the event of a phase-to-ground short-circuit (fault current will be limited to the level of the phase-to-phase short-circuit current). One reactor terminal is connected to the neutral of the network and the other terminal is grounded. During normal operation of the power system the current flow through the reactor is almost zero, since it is only driven by the imbalance of the three-phase network.



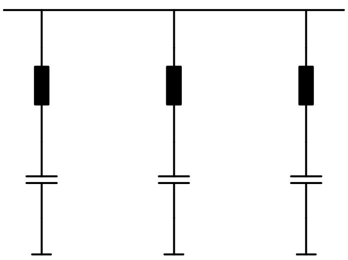
*Neutral grounding reactor*

## 5.3 Harmonic filter reactors

Harmonics are generated by non-linear components and loads in the power system. In electrical power engineering a number of such non-linear loads exist, in components and devices such as welding machines, electronic drive systems or fluorescent lighting.

Harmonic currents may have an adverse effect on different electrical components. These include transformers, switches, capacitors, fuses and relays. The detrimental effects are increased losses and heating and/or excessive dielectric stresses. Electric utilities very often impose high charges when certain maximum levels of harmonic distortion are exceeded.

Therefore harmonic currents have to be eliminated by filters. These harmonic filters, essentially consisting of reactors and capacitors, are usually installed close to the source of harmonics in order to provide a low impedance path for the harmonic currents. This is achieved by series connection of a filter reactor with a capacitor bank, forming a filter circuit tuned to the harmonic frequency which needs to be eliminated. If several harmonic frequencies need to be eliminated, a number of filters with different resonance frequencies will be connected to the bus system, for instance the $3^{rd}$, $5^{th}$ and $7^{th}$ harmonic of the fundamental frequency (50Hz or 60Hz). If fine tuning of the filter is required, the filter reactor may be equipped with taps for inductance adjustment.

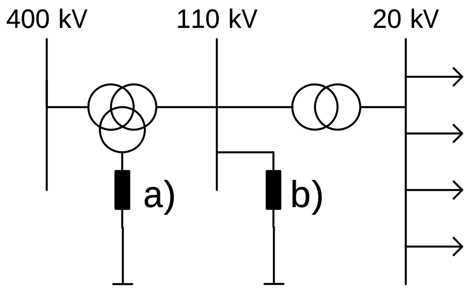



*Typical filter bank*

## 5.4 Shunt reactors

Under normal operation of a power system the current is essentially determined by the connected ohmic and inductive loads. High voltage transmission lines and cables however have an inherent capacitance, causing a capacitive charging current. Thus capacitive VArs are generated. In lightly loaded lines or cables this capacitive current will increase the voltage at the end of the line. By the use of shunt reactors the capacitive VArs will be compensated and the voltage increase at the end of the line will be limited. The efficiency of the power system will be increased by allowing the transmission of more active energy.

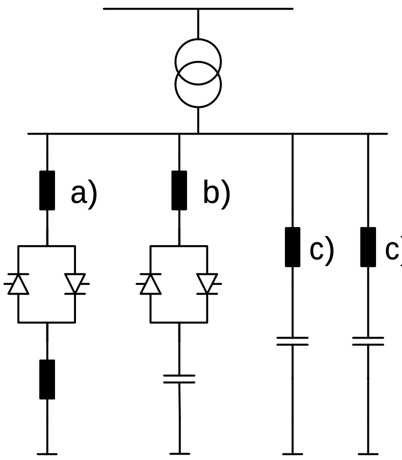
Air-core dry-type shunt reactors are normally connected to the tertiary winding (e.g. at 20 kV) of the high voltage transformer (e.g. 400 kV /110 kV transformers) (a). For system voltages up to 115 kV (in special cases up to 245 kV) air-core dry-type shunt reactors may also be directly connected to the system (b).




*Shunt reactors*

## 5.5 Reactors for Static Var Compensation (SVC)

In order to improve power system transmission and distribution performance and stability Static Var Compensation (SVC-) Systems are installed by electric utilities.




*SVC reactors*

Thyristor controlled reactors (a), called TCRs are major components of an SVC system. They are commonly used in combination with switched shunt capacitors to provide variable reactive power as required. To limit the inrush current of the capacitors, series connected damping reactors (b) are inserted ahead of the capacitor bank. The power semi-conductors used in an SVC scheme generate harmonics, which need to be eliminated by harmonic filters. Therefore in an SVC system harmonic filter reactors (c) are employed as well.

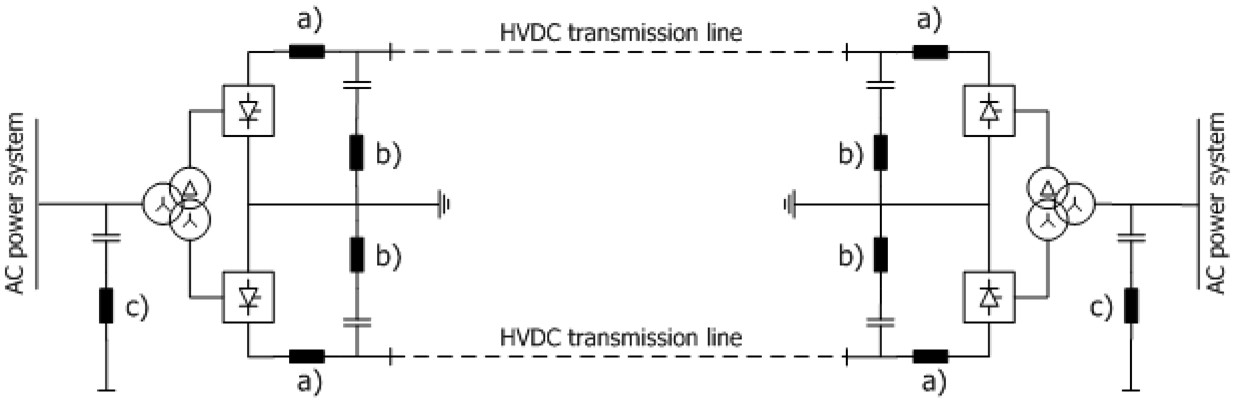
Demands for increased production and more stringent regulations regarding admissible network disturbances make reactive power compensation a profitable solution in industry as well.

A typical example for an industrial load that would cause inconvenience to consumers is an electric arc furnace (EAF) in a steel works. The extreme load fluctuations during the scrap melting process require dynamic reactive power compensation in order to provide stable and steady voltage support for the electric arc furnace and to minimize network disturbances. SVC systems for electric arc furnaces therefore represent the key application for SVC reactors, in particular for thyristor controlled reactors.

## 5.6 Reactors for High Voltage DC Transmission (HVDC)

High-voltage direct current (HVDC-) technology is employed, if electrical bulk power has to be transmitted over long distances by overhead lines or submarine cables. It is also used to interconnect independent AC power systems by so-called back-to-back interconnectors, when traditional alternating AC connections can't be used. This might be the case, if the AC power systems are operating asynchronously or when the traditional AC connection of the power systems would result in a too high short-circuit power level.

In an HVDC system air-core dry-type reactors are major components and are used for various purposes. As an example the one-line diagram below shows a typical HVDC system.




*HVDC reactors*

HVDC smoothing reactors (a) are connected in series with the HVDC transmission line or in the intermediate DC circuit of a back-to-back interconnector. They are installed for the purpose of reducing the harmonic currents in the DC system, reducing the rate of current increase during fault conditions and of improving the dynamic stability of the HVDC system.

HVDC filter reactors are installed on the AC side (c) as well as on the DC side (b) of the converter station. AC filters serve two purposes at the same time, providing reactive power and reducing harmonic currents.

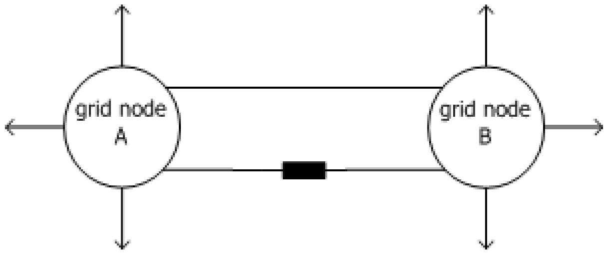
## 5.7 Reactors for Voltage Sourced Converters

In HVDC transmission as well as in SVC Systems, so-called "voltage sourced converters" – or "VSCs" - are increasingly used. Air-core dry-type reactors, such as converter reactors or phase reactors, are implemented here, which have been specially developed to cope with the requirements associated with this new application.

## 5.8 Load flow reactors

The distribution of the load flow in complex interconnected power systems is determined by the voltage levels in the nodes of the electric power grid and the impedance of the transmission path. To optimise and to control the impedance of the transmission path, load flow reactors are connected in series to the high voltage transmission line.

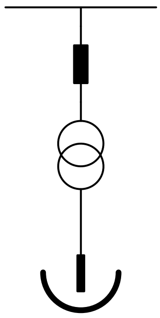
The use of load flow reactors in complex electric power grids is one the most cost-effective solutions to ensure the required load balancing within the grid system under normal continuous load conditions and/or under contingency overloads conditions.




*Load flow reactor*

## 5.9 Series reactor for electric arc furnaces

Series reactors are installed in the feeder system of an electric arc furnace (EAF) on the primary side of the furnace transformer in order to improve the efficiency of the furnace, especially during the melting process. By increasing the source impedance of the EAF power supply, the electric arc will be stabilised, the consumption of the graphite electrodes and the tap-to-tap time (melting cycle) will be reduced. The series reactors are commonly equipped with taps, typically in the range of 40 to 100% of the maximum inductance (usually in steps of 15% or 20%), to optimize the power factor for a certain melting process/cycle.



*EAF reactor*

# 6 Type designation of Coil Innovation air-core dry-type reactors

### Capacitor Reactors

| | |
|---|---|
| CA1 | Standard Capacitor Reactor (Inrush Current Limiting / Damping Reactor), single-phase, side-by-side mounted |
| CA3 | Standard Capacitor Reactor (Inrush Current Limiting / Damping Reactor), 3-phases stacked |
| CAH | Capacitor Reactor for HV-Application (e.g. Discharge Reactor for a series compensation capacitor bank) |
| CV1 | Capacitor Reactor for SVC (TSC Reactor), single-phase, side by side mounted |
| CV3 | Capacitor Reactor for SVC (TSC Reactor), 3-phases stacked |

### Series Reactors

| | |
|---|---|
| CF1 | Standard Load Flow Reactor, single phase, side-by-side mounted |
| CF3 | Standard Load Flow Reactor, 3 phases stacked |
| CFH | Load Flow Reactor for HV Application |
| CL1 | Standard Current Limiting Reactor, single phase, side-by-side mounted |
| CL3 | Standard Current Limiting Reactor, 3 phases stacked |
| CLH | Current Limiting Reactor for HV Application |
| AFR | Series Reactors for Electric Arc Furnace |

### Filter Reactors

| | |
|---|---|
| FR1 | Standard Filter Reactor, single phase, side-by-side mounted |
| FR3 | Standard Filter Reactor, 3 phases stacked |
| FV1 | Filter Reactor for SVC, single phase, side-by-side mounted |
| FV3 | Filter Reactor for SVC, 3 phases stacked |
| FH1 | Filter Reactor for HVDC, single coil |
| FH2 | Filter Reactor for HVDC, two coils stacked (e.g. to allow inductance adjustment) |

### Reactors for Reactive Power Compensation

| | |
|---|---|
| SH1 | Shunt Reactor, single phase, side-by-side mounted |
| SH3 | Shunt Reactor, 3 phases stacked |
| TC1 | Thyristor Controlled (Shunt-) Reactor, single phase, side-by-side mounted |
| TC2 | Thyristor Controlled (Shunt-) Reactor, two coils per phase stacked |
| TC3 | Thyristor Controlled (Shunt-) Reactor, 3 phases stacked |
| PV1 | Phase Reactor for SVC-Light |
| PH1 | Phase Reactor for HVDC-Light |

### DC Reactors

| | |
|---|---|
| DCR | Standard DC-Reactor (LV- & MV Application) |
| DCH | DC-Reactor for HVDC |

### Neutral & Midpoint Reactors

| | |
|---|---|
| NGR | Neutral Grounding Reactor |
| MPH | Midpoint Reactor for HVDC |

### Test Reactors

| | |
|---|---|
| TRC | Test Reactor designed for countinuous duty |
| TRS | Test Reactor designed for short-time duty |