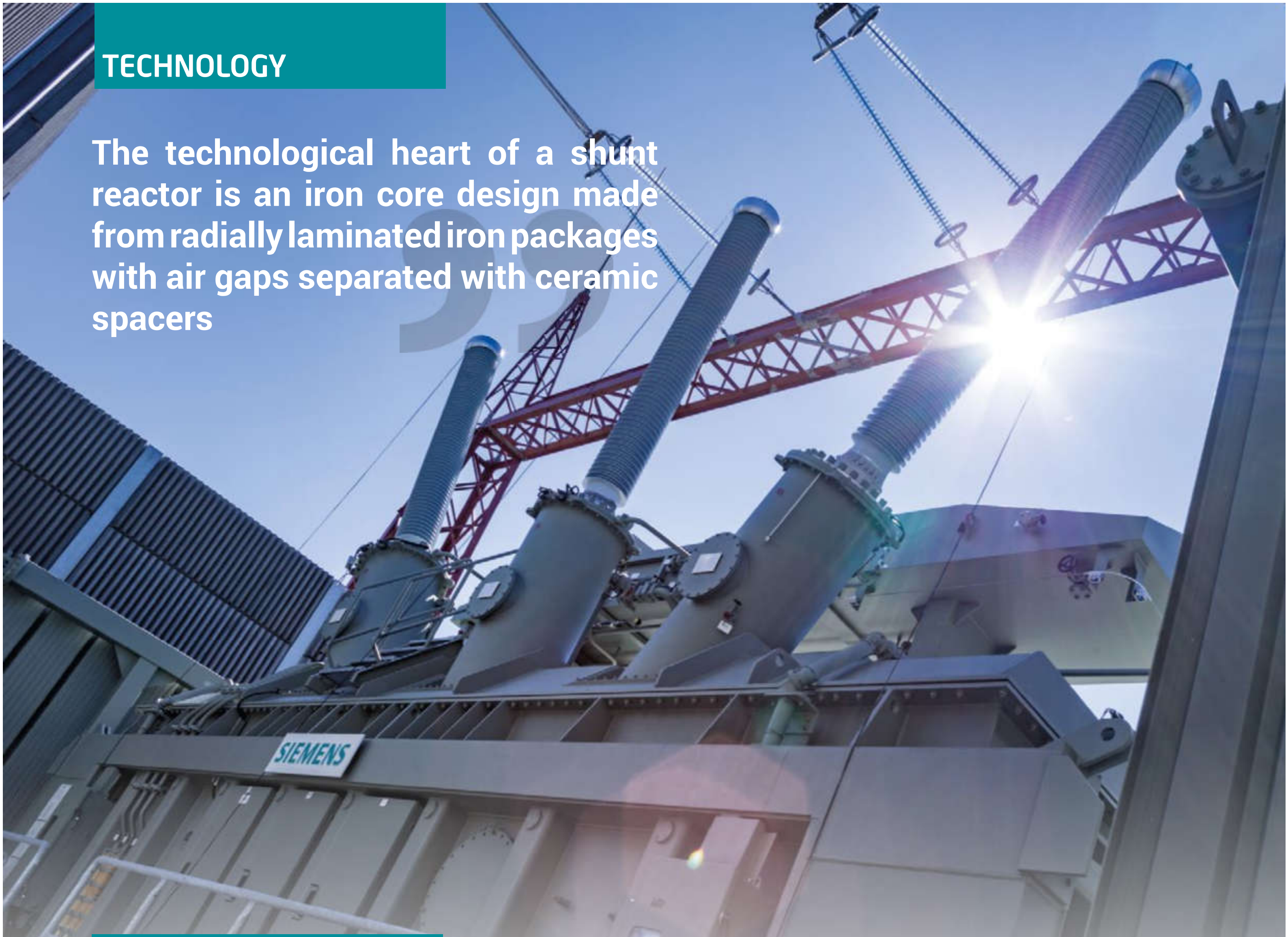


> The technological heart of a shunt reactor is an iron core design made from radially laminated iron packages with air gaps separated with ceramic spacers

Shunt reactor technology: Three world records in three years

Increasing renewable power leads to speedy development of innovations

ABSTRACT

Variable shunt reactors (VSR) with on-line tap changers are a cost-effective solution for compensation of reactive power and maintaining voltage stability, especially with the growing use of renewable power sources characterized by volatile demand of reactive power. Shunt reactor technology is based on an iron core design with air gaps which must be created to ensure mechanical stability with low vibration and noise. The wide regulation range of a VSR provides the correct amount of reactive power in small enough steps to avoid it switching on and off, thus preventing big switching impulses in the grid. For off-shore wind parks, the ester-filled shunt reactor is a promising solution which increases environmental safety.

KEYWORDS

variable shunt reactor, core with air gap, reactive power, renewable sources

1. Introduction

With the increasing infeed of renewable powers, which are fluctuating by nature, a reliable and secure power supply is becoming increasingly challenging. Reactors are a crucial component in meeting current and upcoming challenges. This led to three world records in the last three years.

Shunt reactors are either series reactors or compensating reactors which are used as an inductive load to control

> **Inner clamping with tie rods inserted in the core, and outer clamping outside the core and winding ensure compact designs with minimum vibration and noise**

the voltage and provide reactive power compensation. These reactors are connected between transmission voltage and earth. The target is to have a high inductive power but with small dimensions. Windings, insulation, tank, monitoring equipment and tap-changers are known components of transformer technology. The technological heart and the main difference to a transformer is the core of a reactor. The best and most renowned technology is an iron core design with air gaps, in which only few suppliers have a lot of experience and expertise. This iron core design with air gaps leads to a compact design, with low noise, vibration and losses. Another benefit of the iron core with air gaps is the dampening effect (knee point voltage) that limits voltage under extreme overcurrent conditions. The core is made from radially laminated iron packages, while ceramic spacers ensure precise compliance with the specific air gap requirements. The core is clamped together by tie rods made of steel and/or wooden limbs, and held in place with the iron yoke and return circuit in a clamping frame. High-quality suppliers can offer, design and build two different types of core concepts. The first is inner clamping, where the tie rods are inserted through holes in the core. This results in a compact design at high voltages in particular and, thanks to the optimized force transmission, with a minimum amount of noise. The second is outer clamping concept, where the tie rods are located outside the core and winding which, at low voltages or in single phase reactors, reduces the unit weight (core and winding). In addition, the spring technology between the tie rod and crossbeam ensures core pressing. This results in a constant low vibration and noise level over the entire life of high-quality reactors.

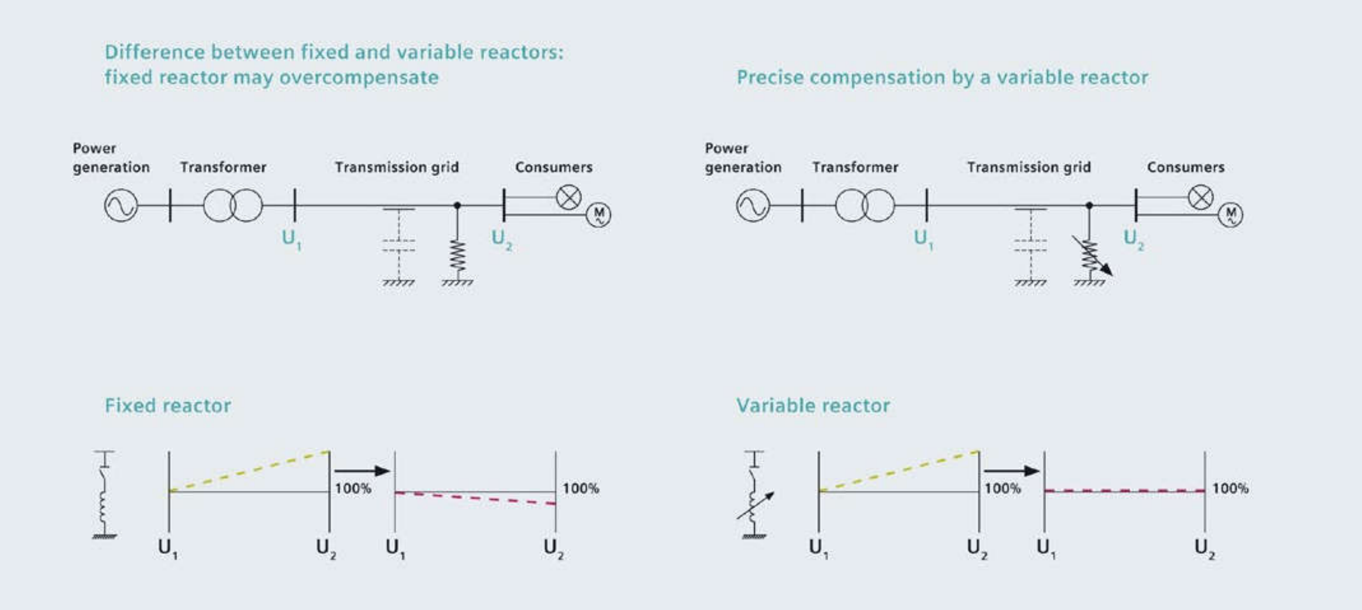
The iron core keeps and concentrates the magnetic flux generated by the windings, which needs to overcome the air gaps. Thanks to the big differences in the permeability of electrical steel and oil, or rather air, it is sufficient to set the magnetic resistance of the air gaps for the series connection of iron and air gaps. Air gaps reduce the inductivity and increase the power of this arrangement.

Shunt reactors can be designed and delivered as fixed or variable units. The fixed reactor allows only for the compensation of constant load and generation conditions, and will be used for HV lines and cables with stable load or generation and fixed line length.

In contrast, variable shunt reactors are equipped with on-load tap-changers (OLTC) which can change the number of connected turns and thereby change and adjust the reactance as well as handle big load fluctuations.

Using an OLTC to render a shunt reactor variable is the most common operation principle. The windings of a variable shunt reactor come with tappings which allow for the connection of more or fewer turns in order to change the reactance. These parts can be arranged separately like the regulation winding of power transformers. VSR (variable shunt reactor) provides a variable reactive power along the regulation range in order to adapt to different local situations and a demand of reactive

Air gapped core of a shunt reactor



Differences of fixed and variable shunt reactors

On-load tap-changer as used in variable shunt reactor (Image courtesy of Maschinenfabrik Reinhausen)

power in the grid, leading to the lowest losses, optimized transmission capacity and improved efficiency of the lines. This is due to the properties of the cables and overhead lines as they are basically capacitive loads, whereby cables have a higher capacity compared to overhead lines – at the same voltage and length – due to their insulation. If a variable shunt reactor compensates a line, the strain to the line can be minimized thanks to the charging capacity, and therefore the transmission losses will be reduced. Another crucial aspect is the effects of voltage change depending on the load at the end of the transmission line. The capacitive load leads to overvoltage on a non-loaded line, which can harm subsequent devices. When the lines are under load, the inductive resistance leads to a voltage drop along lines. The additional inductance of the shunt reactor operates against overvoltages.

With the increasing power demand and the extension of renewable power generation, there is a need for reactive power in many countries. As VSRs need less space than phase shifters or converter stations, they are an attractive solution for network operators. The cost effectiveness in comparison to larger grid extension measures, as well as their robustness and low-maintenance needs, are further advantages of VSRs.

2. 2016 – First tapped variable shunt reactor with 80 % regulation range

For the first shunt reactor with 80 % regulation range, the renewables were the main drivers. The installed assets need to be more flexible than in the past because increasing renewable infeed leads to load fluctuation. Therefore, a big TSO in Germany, a pioneer in flexible design of transmission grids, opted to partner up with the innovation leader in transformer technology and most experienced shunt reactor provider to come up with a variable shunt reactor with 80 % regulation range and 400 kV voltage level in order to meet the upcoming challenges. Thanks to its wide regulation range, the shunt reactor does not need to be turned off and on again in order to get the right amount of reactive power to the grid. This prevents big

Wide regulation range (80 %), high power rating (300 MVA) and the use of ester fluids are the three most important recent achievements

Largest regulation range of 80 % for tapped VSR

switching impulses in the grid caused by switching on and off again. This VSR also supplies enough reactive power during a black start. All of these steps lead to a more resilient and safer grid thanks to the precise reactive power control.

The shunt reactor is built with 33 tapings to cover a rating from 50 MVAr up to 250 MVAr at a voltage level of 400 kV. The most challenging aspects of building this reactor were the winding arrangement, the lead concept to the tap-changer, and the overall dimension and weight of this shunt reactor which are comparable with a large power transformer.

3. 2017 – World's most powerful variable shunt reactor ever built

The second world record – the most powerful variable shunt reactor – was built and successfully tested in 2017. Its key data are the power rating of 120-300 MVAr and a

Variable shunt reactors with OLTCs provide a variable reactive power and ideally support the connection of renewable sources with fluctuating loads to power grids

Biggest variable shunt reactor ever built rated voltage of 220 kV. It weighs 317 tons and the dimensions are approximately 10x8.5x8 meters.

Variable shunt reactors are ideally suited to support the connection of wind farms to existing power grids. By combining the proven design of shunt reactors with the reliability of tap-changers, variable shunt reactors can keep the voltage within the defined voltage band, even when extreme voltage fluctuations occur. This enables grid operators to adapt to the reactive power currently needed and to minimize losses. This shunt reactor will balance the volatile demand of reactive power of the world's largest offshore wind farm. The relatively low sound emissions of less than 84 dB(A) at 300 MVAr also add to the environmental compatibility of the units.

4. 2018 – First ester-filled offshore shunt reactor

The access of offshore wind parks requires special properties of the used equipment. The rough conditions at sea as well as the volatile power production are only two of the main challenges to overcome. The cable connection of the offshore platforms require reactive power control, which makes the use of variable shunt reactors necessary.

Typically, reactors are filled with mineral oil, but the offshore transformers are filled with ester because of ecological/environmental reasons. Together with the ester-filled power transformer, they are installed outside of the platform enclosure.

Considering that ester is an approved and preferred insulation and cooling liquid for power transformers in wind applications, the target was set to develop an ester-filled shunt reactor. Another benefit of ester are its high fire and high flash point as well as a slower aging of solid insulation. Furthermore, the lifetime and operational safety are improved when using ester.

Conclusion

The quest to integrate renewably generated power in existing grids is a challenge, but at the same time it is an exciting basis for the development of innovative features. In collaboration with future-oriented transmission and distribution grid operators, as well as wind park developers, experienced and quality-driven manufacturers can push the limits of what had seemed to be a mature technology. It is however recommended to consider not only CAPEX, but also the best-in-class meantime-between-failure-rates (MTBF) and references as well as the capability for consultancy on the supplier side to make sure that (variable) shunt reactors will work efficiently and economically and pay off during their operation time.

> **Ester-filled shunt reactor is a good solution for off-shore wind parks due to a lower environmental impact, extended lifetime and improved operational safety**

First shunt reactor with ester fluid

Author

Saskia Baumann holds a B.Eng in Mechanical Engineering and an MBA. She joined Siemens in 2011 and has been working in various positions within the distribution transformers. Currently she is the responsible product manager for shunt reactor within the large power transformer segment.