Grid Solutions

REDUCING FAULT CURRENTS IN POWER SYSTEMS WITH AIR CORE SERIES REACTORS

GE VERNOVA

I. INTRODUCTION

Power plant expansions and new generation additions may result in higher short-circuit levels that existing transmission/distribution systems can struggle to handle without upgrading equipment or limiting the added fault current.

Current-limiting reactors reduce fault currents to compatible levels that existing equipment can handle. This eliminates the need for equipment replacement and is proven to be one of the most cost-effective solutions. The inductive reactance's ohm magnitude impacts the protection and blocking level of the fault current; it also influences the continuous operation voltage drop created by the new impedance. Power flow control reactors, which are series-connected to transmission lines, regulate the current into two or more parallel circuits. Series reactors can also be used for many other applications such as capacitor banks inrush/outrush, motor-starting and arc-furnace current limiting, or as part of series compensation discharge circuits.

This document presents useful information on the application - describing the voltage regulation and fault limit reduction with series reactors – as well as some practical aspects of implementing these inductors in power systems.

Benefits of Air Core Dry Type Series Reactors

Air core, dry type series reactors are commonly used in systems with voltages up to 800 kV and are typically connected in series with transmission lines or distribution feeders. As impedance of air core reactors doesn't vary due to core saturation, most medium-/high voltage series reactors are dry type, air core. For low-voltage application, iron-core, dry type reactors may be required due to limited installation space. For very high voltage and power, current-limiting reactors may use iron core, oil-immersed technology.

As power, voltage, and available space allow, the benefits of air core, dry type series reactors include:

- no magnetic core saturation during short-circuit
- low maintenance requirements and environmentally friendly
- oil treatment collection systems are not required
- simple transportation, usually not requiring special permits or hauling
- simple erection and commissioning
- most cost-effective solution with shorter lead time
- simple protection requirements

Additionally, Grid Solutions at GE Vernova's air core reactors offer further benefits, including:

- conservative temperature rise for extended service life
- conservative voltage drop limit between terminals, along surface
- surface treatment for protection against UV radiation and pollution
- customized space-saving solutions for installation in compact areas
- high mechanical strength to withstand elevated short-circuit forces
- first-class materials resulting in high operative availability

Handling, installation, and commissioning details of Grid Solutions air core reactors can be provided upon request.

II. DESIGN AND TECHNOLOGY

Low-power series reactors usually present low impedance and current levels. To create the most compact solution, the air core reactors for this application are designed using fiberglass encapsulated (FED) technology.

FED technology reactor windings consist of numerous insulated aluminum conductors. These conductors are mechanically immobilized and encapsulated in epoxy impregnated fiberglass filaments, forming cylinders. Depending on the reactor's ratings, one or more cylinders are connected in parallel between the aluminum spiders. The individual cylinders are separated by vertically oriented fiberglass spacers, forming cooling ducts that allow air flow from bottom to top, dissipating heat. This technology allows compact coils for high inductance, reducing the installation footprint.

High-power series reactors usually present high impedance and current levels. Air core reactors developed for this application are designed using multi-wire cable design (MCD) cables, which offer low losses.

The MCD technology reactor's winding consists of insulated aluminum stranded cables and follows a very similar manufacturing process to FED. MCD technology is mainly recommended for high current, reducing losses considerably.

Air core reactors are highly customized equipment, and many different accessories may be part of a design. Figure 1 illustrates the standard design of a series air core reactor.

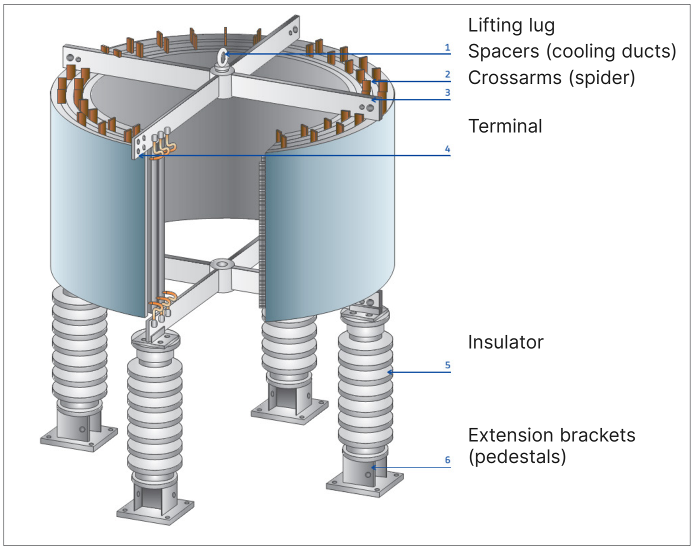


Figure 1: Standard design of an air core reactor.

Application of Series Reactors

Series reactors are mainly used to:

- Reduce/limit fault currents
- Match impedance of parallel feeders

Series reactors require integration into the electricity network. This requires consideration of aspects such as physical layout, protection coordination, and voltage control.

This brief describes some aspects in applications where series reactors are installed.

III. CASE STUDIES

Series reactors are used extensively in transmission and distribution networks to ensure that fault ratings are not exceeded. For example, when generation capacity is expanded or when feeders are added to a substation, the resulting fault current may exceed the rating of existing equipment.

The effect and implications of series connected current limiting reactors can best be described in the light of a specific example.

Case Study 1 - System Expansion and New Generation

A simplified representation of a section of a power system network is shown in Figure 2. The network has been augmented by means of an additional feeder (OH2) from a transmission substation to a distribution zone substation. The additional feeder is required to cope with load growth in the distribution network. The fault rating of cables and switchgear on the primary side of the zone substation is stated as 16 kA at 66 kV.

Before the overhead line OH2 was installed, the fault level at the 66 kV side of the zone substation was 12.0 kA. This is substantially less than the rated fault withstanding level of 16 kA.

When the second 66 kV side is connected as shown, the fault level at S66_1 increases to 26 kA, well over the rated value. Upgrading switchgear, cabling, busbars, and other primary equipment to the higher fault level would be time-consuming and expensive.

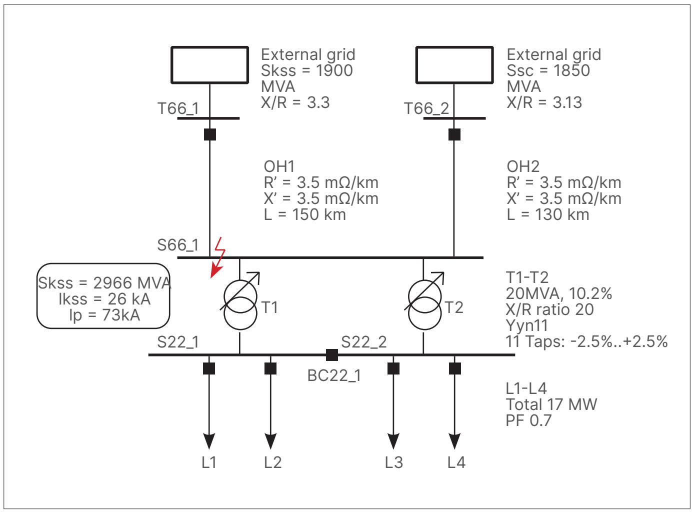


Figure 2: Simplified representation of a power network.

Fault Limiting Reactors

A simple and reliable solution in this example is to install fault current limiting reactors in series with both lines. Such a solution is shown in Figure 3. The reactor impedance has been selected such that the highest fault level is less than 10 kA, without consideration of the contribution of rotating loads in the network.

Placing a 2.5 Ω reactance in series with both feeders results in a fault current of 9.8 kA, well within limits. The goal of additional power capacity and restricted fault current is therefore achieved with the combination of a new feeder and a series reactor.

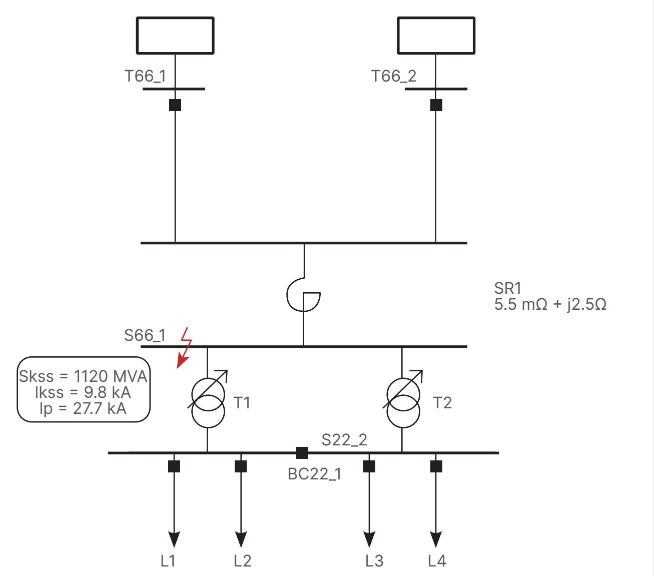
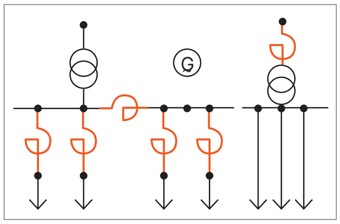


Figure 3: Simplified representation of a power network with a series reactor added.

The reactor's impedance can be calculated using the following equations:



$$X_L = V_N^2 \left(\frac{1}{S_{SC_{AFTER}}} - \frac{1}{S_{SC_{BEFORE}}} \right)$$

$$X_L = \frac{V_N}{\sqrt{3}} \left(\frac{1}{I_{SC_{AFTER}}} - \frac{1}{I_{SC_{BEFORE}}} \right)$$

Figure 4: Formulas for calculating a reactor's impedance.

If the reactor impedance is available but thermal fault current is not provided, this current can be calculated by the following formula:

$$Ithermal = \frac{V_{MAX}}{\sqrt{3}\, x(Zreactor + Zsystem)}$$

Zsystem can be calculated based on the existing available short-circuit power/current of the system.

$$Zsystem = \frac{Vsystem}{\sqrt{3} xIscsystem} = \frac{Vsystem^2}{MVAsystem}$$

Case study 2 – Voltage Regulation

The addition of a series reactor will result in a voltage drop related to the impedance of the reactor. In most cases, this voltage drop is small compared to the normal system voltage fluctuations and no additional action is required. The voltage drop across the reactor for a combined zone substation loading of 17 MW at a power factor of 0.7 is approximately 1%, as shown in Figure 4.

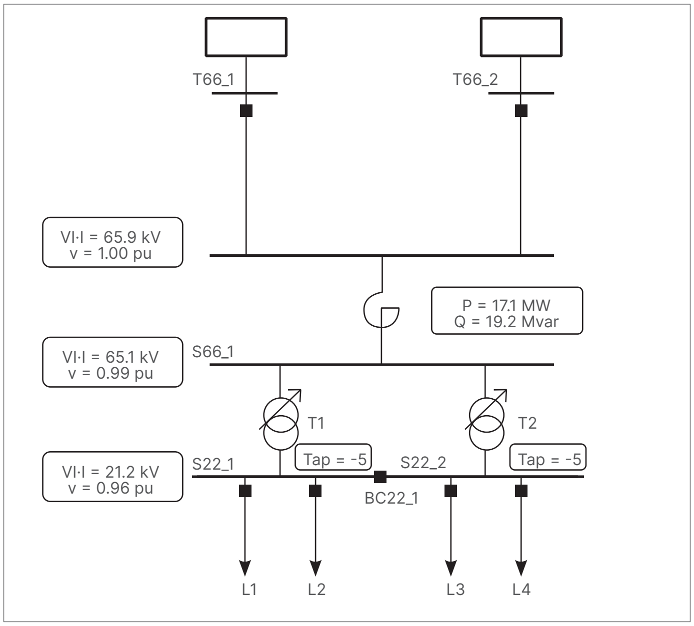


Figure 5: Voltage drop after the addition of the series reactor.

The two zone substation transformers have on-load tap changers configured to maintain the voltage of the 22 kV busbar within a narrow range.

In this case, the tap changers have reached the tap limit of -5, and the voltage of the 22 kV buses has dropped to 0.96 p.u. This may be unacceptable, since the tap changers will not be able to cope with any additional voltage reduction.

A solution is shown in the single line diagram below.

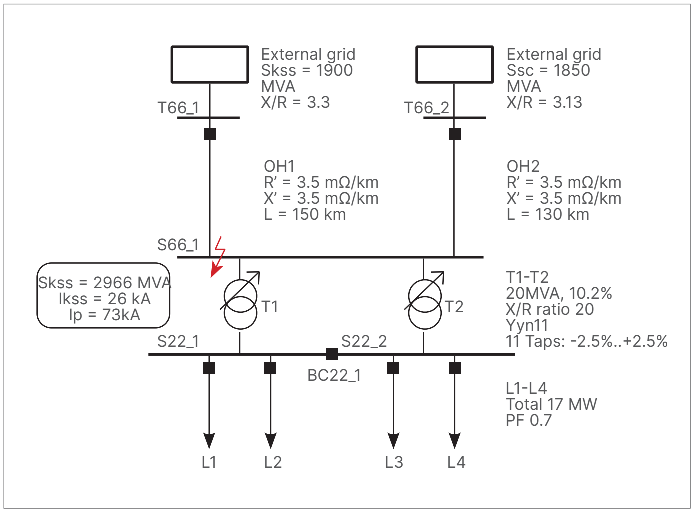


Figure 6: Voltage regulation with capacitor banks added.

Improving the power factor of the zone substation load to 0.93 or better results in excellent voltage regulation and allows the system to operate within the tapping range of the transformer. With the addition of correctly sized shunt capacitor banks, the 22 kV busbar voltage is improved to 0.99 p.u. and the transformer taps are at position -2.

Practical Considerations

The following additional aspects should be taken into account when studying and designing series reactor installations:

1. Voltage drop across the reactor must be considered, as should how voltage regulation can be maintained when series reactors are connected.
2. Appropriate magnetic and electrical clearances between reactors and other substation equipment must be observed, and all footings must be designed for use together with air core reactors. Consult the product manual for complete details required from receiving to commissioning.

IV. CONCLUSION

This application brief describes in simple terms the benefits of installing series–connected current limiting reactors. It is shown that additional network capacity can be made available without the need for costly upgrades of the existing primary plant.

When a series reactor is connected to the network, there may be a resulting voltage drop. The reality is that these voltage drops are, in most cases, quite small. In cases where the voltage drop is excessive, shunt capacitor banks can be used to improve the power factor of the load and improve voltage regulation.

Determining the appropriate impedance for a fault current limiting reactor is a relatively simple exercise. To ensure a successful installation, care must be taken to consider all aspects of the application.

GE can assist you in selecting the correct series reactor for your application, and provide advice on the best way to integrate the reactors into your network. Our factories are able to supply air core series reactors for electrical systems with rated voltages up to 800 kV. Grid Solutions’ top-class at GE Vernova top class materials are associated with more than 50 years of know-how, conservative temperature rise and conservative voltage stress, making them one of the market’s best options for dry type, air core series reactors.

References/Standards for Design, Manufacturing, and Testing:

IEEE Std. C57.16-2011 – IEEE Standard for Requirements, Terminology, and Test Code for Dry-Type Air-Core Series-Connected Reactors

IEEE Std. C95.6-2002 – IEEE Standard for Safety Levels With Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz

ICNIRP Guidelines 2010 – Guidelines for limiting exposure to time-varying electric and magnetic fields (1 Hz to 100 kHz)

IEC 60076-6:2007 – Power transformers - Part 6: Reactors

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