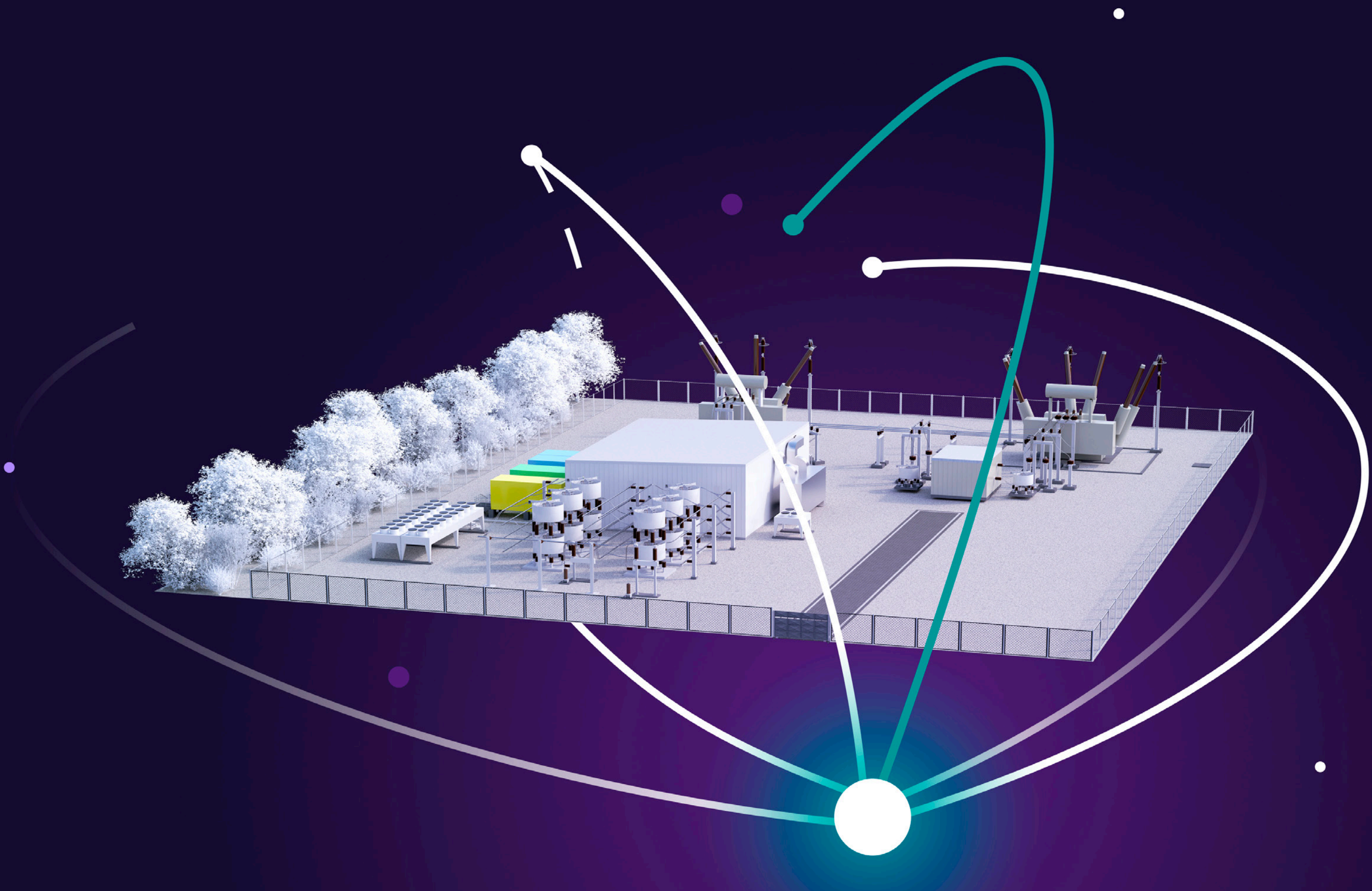
UPFC PLUS

Enhancing transmission grid stability and reliability through dynamic load flow control



Content

1. Abstract

Enhancing transmission grid stability and reliability through dynamic load flow control

Energy ecosystems around the world are in a state of profound change. Reliable electricity is a basic requirement for societies. While details may vary from country to country, and even from supply area to supply area, there are three common challenges for grid operators and power producers. Underdeveloped or weak grids, mature and ageing infrastructure and liberalised markets including a growing share of alternative energy sources, leading to the associated disruption to business models.

2. Modern challenges for a legacy power grid

There are three major trends that are currently challenging the transmission system and will continue to do so in the future. This trio of developments in the form of decarbonisation, decentralisation and deregulation are well known and understood but they still present Transmission System Operators (TSOs) with numerous problems.

According to the International Energy Agency (IEA), world gross electricity production was 3.9 per cent higher in 2018 than the previous year. Year on year, global electricity production has grown continuously since 1974, While energy demand is growing significantly, driven by electrification and sector coupling, the generation landscape shifting with fossil and nuclear power being replaced by renewable energy sources.

The transmission grid was constructed decades ago to manage electricity from conventional and nuclear-fuelled plants that were located near to major load centres. In recent years that has changed with increasing amounts of decentralised renewable generating assets coming online in areas where the grid was never designed to handle high and volatile loads. This is resulting in many lines that are under increasing pressure to carry heavy loads while other networks are now not fully utilised as they were used to be.

The rise of non-linear, distributed systems with a growing share of renewable infeed in parallel to the diminishing role for centralised generation has brought about a degree of complexity not previously seen. Grid operators need to cope with bidirectional load flows and intermittent infeed. They must bridge increasingly long distances between generation and load and enable energy exchange among different energy systems. At the same time, grid operators need to be as efficient as possible and develop new business models to ensure long-term profitability. They also must meet sustainability goals and seek financing options that help implement the required technologies.

The third challenge is deregulation that has created meshed grids with energy exchange between countries and regions becoming more important. This has resulted in high price differentials between market areas. Set against this growing demand and ageing, passive infrastructure, grid stability and resilience is a major challenge.

The traditional market and business models that have served the industry well for many decades are increasingly being disrupted by the growing tide of market liberalisation. New players, as well as new business and collaboration models are entering the markets.

3. Overcoming network constraints

Building new power lines is difficult, no-one wants new overhead cables, and HVDC lines are costly. The approval process for high-voltage power lines takes around ten years and is fraught with challenges. Once recent example came in Germany where TSO, 50Hertz, had a vital 115km, 300kv transmission line from Uckermark to Berlin delayed by six years because of nature conservation concerns. There are other options available to TSOs such as securing power from neighbouring regions through interconnections or redispatch, whereby power is purchased from conventional or peak power plants. This option is expensive with the cost per kw/hr climbing by 30 per cent since 2017 and likely to continue increasing in the near future.

The additional costs incurred in redispatch measures are passed through network usage charges from the TSOs to the end customers. Electricity is therefore becoming more expensive for consumers. According to the Federal Network Agency, the share of network charges in the price of electricity for household customers rose from an average of 5.75 ct/kWh to 7.31 ct/kWh between 2011 and 2017. The economic damage caused by redispatch is enormous in total: the costs were already around 18 billion euros in 2017.

Upgraded capacity on existing lines or new power supply infrastructure are required to connect the demands for power that are and will be growing, and the new decentralised energy sources. In some regions, grid operators are challenged to strengthen the grid infrastructure in a fast-tracked, yet cost-efficient manner.

In light of these developments, new business models that support an economically viable role in this reshuffled energy ecosystem are required. This challenge extends beyond grid operation. Power producers are required to broaden their capabilities to optimise asset performance and explore new opportunities, including grid services, quick responses to fluctuating power demand and storage and beside all that, to ensure grid stability.

4. Calculating grid capacity (n-1)

For all grid operators the goal is to ensure that they operate a stable and reliable system, but this needs to be balanced against costs. To achieve this there needs to be a standard for an acceptable reliability level that can assure, with a high probability, that the voltage and frequency remain within an acceptable range.
That standard is the n-1 criteria. This states that a system can tolerate at all times an unexpected failure or outage of a single system component. This principle has achieved acceptable results over the past decades.

This limit is calculated for each network and the actual figures varies from 50 to 70 per cent constant operation below the thermal limit to ensure that the load in the transmission line does not exceed parameters. With this limit, you guarantee that whenever a fault or outage occurs then the load in the remaining transmission line should not exceed more than 100 percent of the thermal limit. With the increased penetration of intermittent renewable generation and complexity to transmit this energy in dynamic situations that cannot be predicted, transmission lines can often violate this n-1 criterion. To maintain grid stability, it is vital that operators can manage this growing problem.

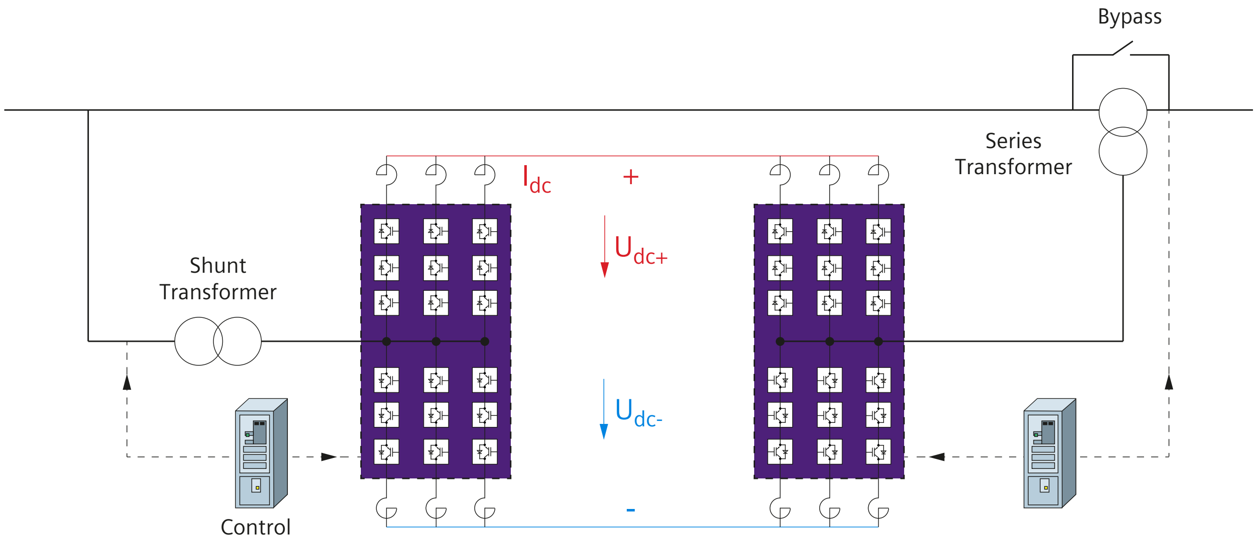
5. Current options for load management

There are four requirements for efficient dynamic load flow management in transmission grids – flexibility, dynamic control, compact installation, and efficiency.

- Flexible: the device needs to have sufficient flexibility to operate within various scenarios that may occur in the future on a rapidly evolving power grid.
- Dynamic control: the device needs fast response to maintain system integrity during switch over and fault conditions.
- Compact installation: the device needs to be compact and incorporate several functions within one unit.
- Efficiency: the device must have low operational costs, low impact and be easy to install & maintain.

There are several technologies currently available and all are well proven and work well in the correct use cases, but all have drawbacks and fail to meet all of the four key criteria.

- Thyristor controlled series capacitors (TCSC): The TCSC works by actively changing the impedance so that it becomes possible to damp power oscillations (POD) and to mitigate sub-synchronous resonance (SSR). Both are important for the stability and safety of generators in the grid, which could be harmed by the interaction of eigenfrequencies with the resonance frequency of the compensated line. The TCSC also enables specific line compensation when operating in steady state. However, it is a large installation with limited controllability and also generates harmonics.
- Phase shift transformers (PST): In power grids, PSTs provide active power flow control. By enforcing or blocking loads, they not only improve the stability and flexibility of grids but also help grid operators get the most out of existing hardware. However, PSTs have slow response times and limited dynamic capability. They cannot provide reactive power compensation so additional technology is required.
- HVDC systems with converter stations: HVDC systems provide transmission system operators with an exceptionally economical and efficient opportunity to supply load centres. Such a bulk power transmission system delivers the required amounts of power, stabilises heavily strained AC grids, and establishes an interconnected power system across regions and countries. They are, however, extremely large installations, huge invests a full through power rating is required.
- Distributed series compensation: For decades, series compensation (SC) technology has improved grid stability and contributed to the optimal utilisation of transmission lines. TSOs around the world have already benefited from solutions that were tailored to their specific requirements. Among the main benefits of series compensation are the reduction of line voltage drops, limitation of load-dependent drops, and a reduction of the transmission angle. However, they have limited dynamic capabilities, large quantities are required to work effectively and again they cannot provide reactive power compensation.



6. UPFC (Unified Power Flow Controller) the missing piece to the puzzle

To effectively manage the transmission system and provide the stability and resilience required means operators must better utilise existing assets. This can be achieved by employing a dynamic load flow management solution such as UPFC (unified power flow controller) which is extremely faster to react and can manage both series and parallel compensation to keep lines within the n-1 criterion and the electricity flowing.

The UPFC can balance load flow in the AC grid, rapidly bypass overloaded line sections, provide reactive power and dynamic voltage control, and utilise assets to physical limits without the need for safety margins.

The UPFC is arranged as two voltage sources. One in parallel that controls voltage and one in series connected to the AC line. It provides reactive power compensation, voltage control and active power load flow control in one unit.

The system comprises of four main components:

1. The converter arrangement as a symmetrical monopole, back-to-back with the DC link. The back-to-back connection is the same installation as an HVDC system but here it serves a different purpose and has different controls.
2. Modular multilevel IGBT Voltage Sourced Converter (VSC) to achieve voltage level.
3. The series transformer injects the voltage into the transmission line to either reduce or increase the current flow through the system.
4. The shunt transformer controls the voltage and the infeed reactive power so that the voltage will remain within the plus or minus 10 per cent limits.

7. Series and parallel compensation

Series side

Series is controlled to any operating point within the circle around Us.
Series voltage injection controls load flow.
100 per cent active power injection 0° or 180° to Ir
100 per cent Reactive power injection 90° or 270° to Ir

Parallel side

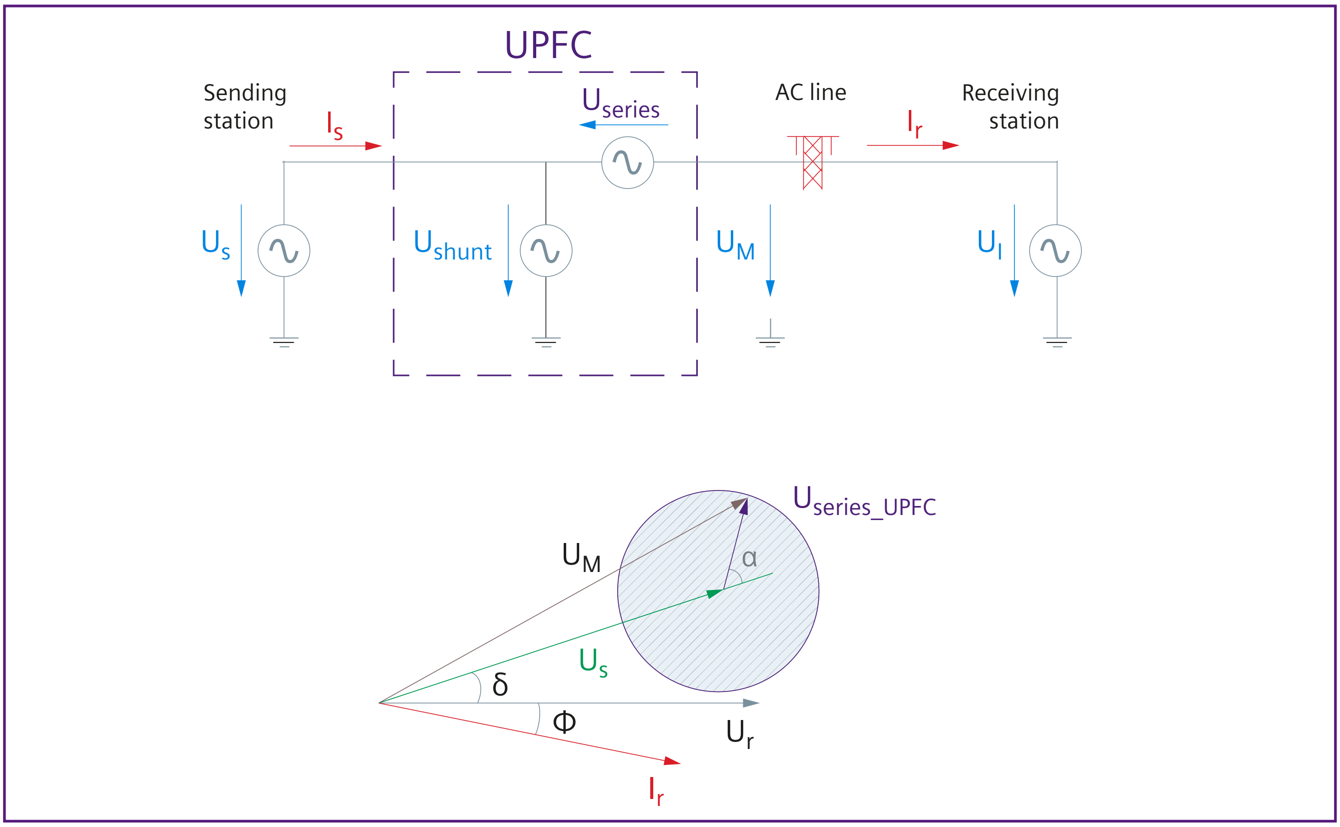
Voltage/reactive power control like STATCOM
Active power transfer through DC-Link

Include

Rapid response time

When managing a fully loaded network during a fault, the line loading will be at 100 per cent which will cause a voltage drop. Because of this, reactive power will need to be provided to ensure stability. Also, when managing or changing the load flow during a network fault it is possible that there will be some stability problems in the transmission line or network that will require insertion of active damping. The UPFC provides active damping by injecting a voltage with a controlled magnitude and angle to ensure that the line and voltage are in phase.

With a UPFC the load can be balanced across numerous lines in milliseconds. When the network is healthy there is no time pressure to balance the flow, this can often be in the range of several minutes, but when a fault occurs you must act in milliseconds. The first requirement for any active or dynamic load flow management is to perform the load flow management in two time zones, both for slow control and fast control.



This is where UPFC outperforms other flow management components. In the field of dynamic load flow management, it supplies fast response in terms of active power management, coordinated reactive power control and can insert active damping to ensure stability.

For effective dynamic load flow management, a response time in milliseconds is required to balance the load during the fault condition and manage the network integrity in terms of stability and thermal limits. This is achieved by the voltage source converter, which is one of the main components of the UPFC system.

8. Summary of UPFC benefits

The UPFC PLUS applies the features and advantages of the well proven Voltage Sourced Converter (VSC) technology with its advanced control, high availability and reduced costs due to systematic standardization.

- It provides answer to today's urgent challenges to keep the grid stable with
- Load flow control in AC grids
- Reactive power compensation and voltage support for different voltage levels
- Fast reaction time in ms
- Controlling of up to 300 per cent of its installed power capacity
- Cost-efficient and a space saving solution

UPFC PLUS can easily be implemented in an existing grid and allows fast reaction times for an efficient load flow management. With this option and the high dynamic control assets can be operated closer to physical limits.

Thus, UPFC is an innovative solution to comply with the growing requirements to the grid with dynamic load flow management that adapts easily to changing infeed from renewable sources by fluctuating consumption, even in case of faults in the infrastructure.

Impressum

www.siemens-energy.com/upfcplus

Publisher:
Siemens Gas and Power GmbH & Co. KG
Werner-von-Siemens-Straße 1
80333 München, Germany

Siemens Energy, Inc.
15375 Memorial Drive, Suite 700
Houston, Texas 77079, USA

For more information, please contact:
support.energy@siemens.com

Editors:
Daniela Preiß, Bernd Niemann

Authors:
Kunal Sharma, Dr. Christian Pfeifer, German Kuhn

Graphics:
Bluebird-Alliance GmbH, Neuss, Germany and Siemens Gas and Power GmbH & Co. KG

Siemens Gas and Power GmbH & Co. KG is the global energy business of the Siemens group, which has been working with its customers on solutions for the evolving demands of industry and society for more than 150 years. With planned stock listing, Siemens' energy business will operate independently as Siemens Energy in the future.
It will offer broad expertise across the entire energy value chain, along with a comprehensive portfolio for utilities, independent power producers, transmission system operators, the oil and gas industry, and other energy-intensive industries. With its products, solutions, systems, and services, Siemens Energy will address the extraction, processing, and transport of oil and gas as well as power and heat generation in central and distributed thermal power plants, and power transmission and technologies for the energy transformation, including storage and sector-coupling solutions. The majority stake in Siemens Gamesa Renewable Energy will round out its future-oriented portfolio. With its commitment to leading the way in decarbonization of the global energy system, Siemens Energy will be a partner of choice for companies, governments, and customers on their path to a more sustainable future. With around 90,000 employees worldwide, Siemens Energy will help shape the energy systems of today and tomorrow.
www.siemens-energy.com