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UPFC PLUS – Dynamic Load flow Management to increase utilization of transmission assets.

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SUMMARY

This paper will explain how Siemens Energy is tackling the advanced grid control challenge through the recently developed and state of the art UPFC PLUS system as a dynamic and intelligent grid 'debottlenecking device' to serve its purpose by dynamic load flow control in the transmission networks. First the paper explains why there is a growing need for dynamic load flow control. The following chapters are about the concept of the UPFC PLUS, its design and finally the control and protection of this solution.

KEYWORDS

Modular Multi-Level Converter, Power electronics, Power system stability, Power flow control, AC Transmission, Reactive Power Compensation

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1. Nomenclature

UPFC:	Unified Power Flow Controller
UPFC	PLUS: Siemens UPFC solution
MMC:	Modular Multilevel Converter
FACTS:	Flexible AC Transmission Systems
MOV:	Metal Oxide Varistor

2. Introduction

The industry is adapting to the technological changes and Canada's grid size and complexity becomes larger year after year. Enhancing transmission grid stability and reliability through dynamic load flow control is important because energy ecosystem across Canada is in a state of profound change. Reliable electricity is a basic requirement for societies.
Transmission grids are operated with N-1 criteria where grid reliability and security are traditionally ensured at cost of underutilized assets [1].
Here, transmission lines can be loaded up to a certain percentage of their physical limit to ensure reliability and security of the system under fault condition. The result is that the grid is underutilized to provide enough margin to manage the impact of a failure in the grid, which is indicated in Figure 1 a) and b). However, current operational philosophy of transmission grid is getting questionable because of high and quick renewable and other decentralized generation penetration in deregulated market.
Also, the utilization of assets up to their physical limit is mandatory to solve the problem of congestion by which finally end consumers are bearing high penalty due to redispatch [2]. Furthermore, a higher utilization of the lines can lead to instabilities in the grid. In such a situation a very fast load flow management is required to ensure the continuation of sufficient load flow and to avoid harmful impact on further parts of the grid. Figure 1 c) and d) show a transmission system being able to transmit more power and ensure N-1 criteria by using dynamic load flow control in selected lines.

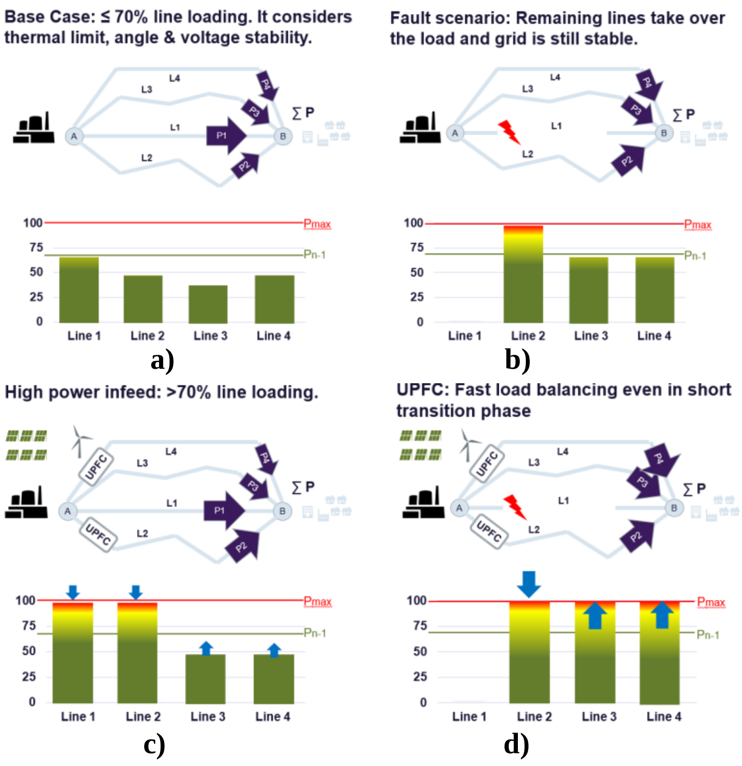

Figure 1: Simplified transmission system with and without dynamic load flow control

Load flow controllers are required to bring the grid where it is fully utilized and reliable and a secure operation is ensured. A load flow controller in the transmission grids should have the following performances:

Dynamic active power control: Controller should provide slow control during steady state condition as well as fast control during short transition phase.

Coordinated reactive power control: Coordinated reactive power support is needed because lines will be loaded more during short transition phase.

Overload capability: The controller must be able to handle overload conditions of transmission line.

Fault ride through/ Post fault recovery: Controller must support fault recovery of transmission system.

Effective stability functions: Controller must contain functions to support angle and voltage stability.

3. Configuration of the UPFC PLUS

Dynamic load flow management with the required performances can be provided by an UPFC PLUS developed by Siemens Energy.

The concept of the UPFC PLUS can be explained in a simplified single line diagram of a transmission line. Figure 2 shows a single line of a transmission system consisting of a sending and a receiving end voltage source, a transmission line in-between and the UPFC PLUS connected at the sending station while represented by two independent voltage sources. One voltage source of the UPFC PLUS is connected as shunt and named U_{shunt}, the other is connected in series to the transmission line and named U_{series}. The shunt part of this system now has the capability to control the voltage at the sending station by absorbing or injecting reactive power. The shunt part can also be seen as a STATCOM. The series part injects a voltage in series to the current depended voltage drop across the line impedance and therefore influences the load flow through the line by virtually increasing or decreasing the line impedance.

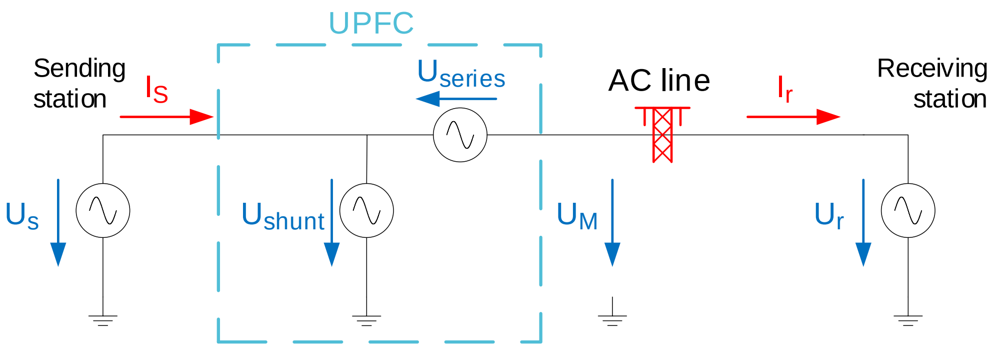

Figure 2: Single line of a transmission line incl. UPFC PLUS

In the real world the system configuration of these two voltage sources is realized by a symmetrical monopole based on voltage sourced MMC which are connected in a back-to-back- arrangement [3]. These two VSC converters are connected to an AC line. The shunt side is connected via a shunt transformer and the series converter via a series transformer. The serial part of the UPFC PLUS is protected by thyristor bypass switch in case of severe line faults. Other integral components of UPFC PLUS are phase reactor, cooling system, charging resistor, high voltage equipment’s, current transformers and control system. Due to the mentioned back-to-back-arrangement of the two converters the system can exchange active power and the series injected voltage can have any angle α from 0° to 360° see Figure 3.

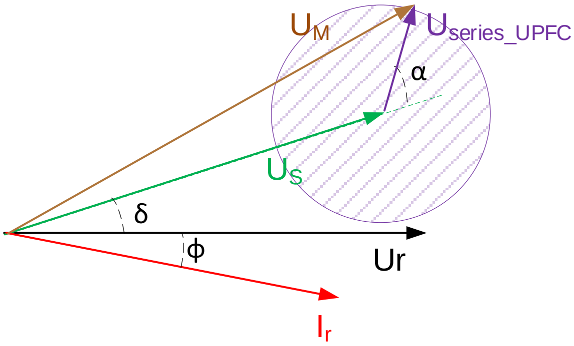

Figure 3: Voltage diagram of UPFC PLUS

The ability to inject a series voltage with active component is a key performance factor of the UPFC PLUS because therefore it is possible to actively damp power oscillations in AC transmission grids.
Figure 4 gives an overview about the physical arrangement of the UPFC PLUS components.

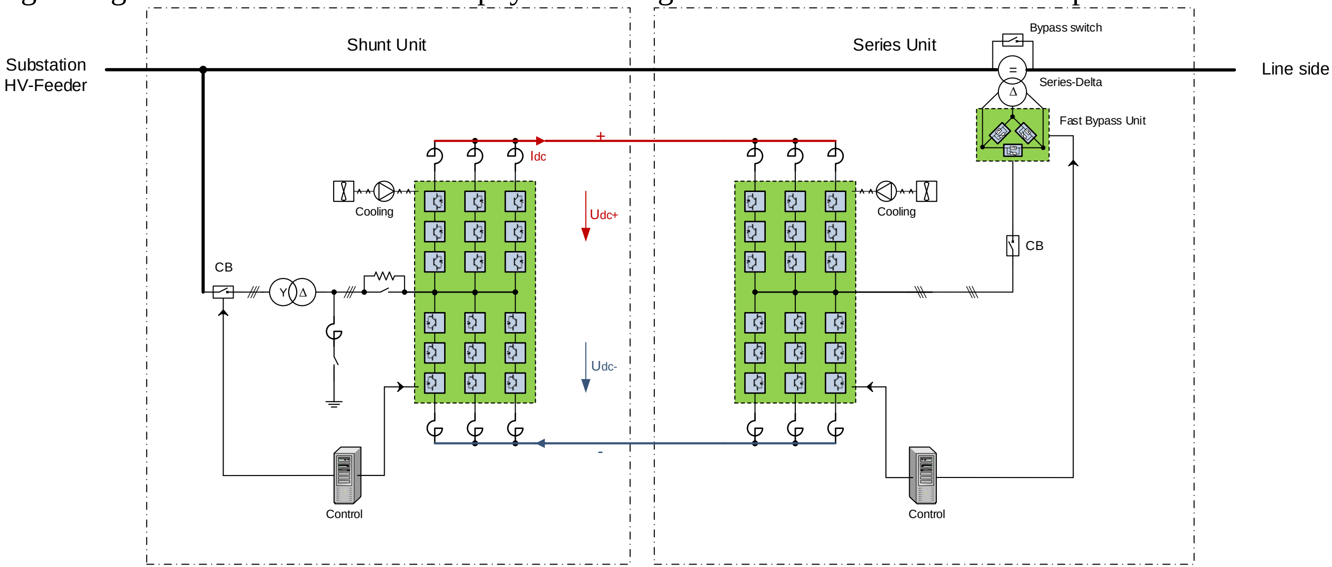

Figure 4: Physical arrangement of the UPFC PLUS

Siemens Energy emphasizes a modular concept in the design of UPFC PLUS to achieve technical & economical optimized solution [4]. The design concept ensures highest performance in proven quality of HVDC and FACTS installation where the MMC technology is dominating the market. Low harmonic interaction with the AC network, robust module design and superior dynamic behavior are the main benefits among others.

4. Control and Protection of a UPFC PLUS

As already mentioned before, the two voltage sources are operating independent from each other. Series converters inject variable voltage from minimum to maximum voltage with variable angle 0-360°, therefore P-Q chart of series converter is a circle, where P-Q chart of shunt converter is a rectangular as per conventional HVDC with VSCs, Figure 5.

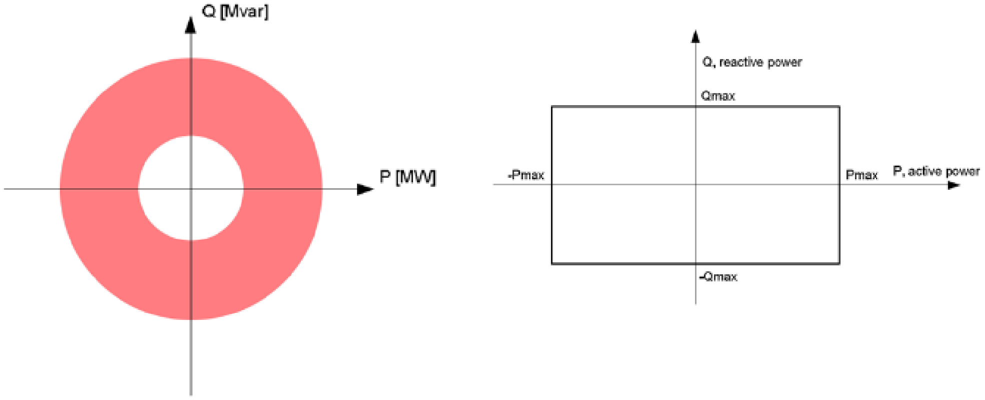

Figure 5: P-Q Diagram of series and shunt converter

From the operating diagram three different control modes for the system operator can be derived:
Current Control: The operator provides the reference value for the current flow in the transmission line.
Virtual Impedance: The operator defines a desired impedance behavior of the transmission line which should be emulated by the UPFC.
Power Control: The operator sets the desired active and reactive power flow at the receiving end of the UPFC as per Figure 4. Instead of defining the reactive power explicitly, the operator can alternatively provide the desired voltage level at the receiving end.

For each of these control modes, the system operator might also define a set-point for the reactive power or the voltage level at the sending end of the UPFC, which can be controlled independently from the other set-points.

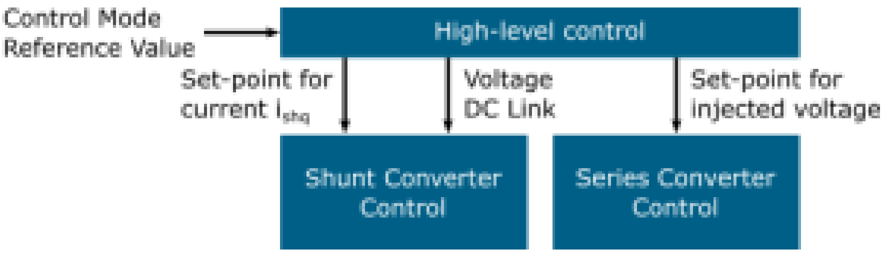

Figure 6: Control layout of UPFC PLUS

Figure 6 shows the three different components involved in the control of the UPFC. The high-level control implements the afore mentioned control modes. Both converters are individually controlled by their own current control system. The series converter receives the set-point for the injected voltage from the high-level control. The shunt converter does not receive a direct input from the high-level control but rather balances the active power requirement of the series converter. Besides the DC-link voltage parameter, the shunt converter also controls the voltage at the sending end by injecting or withdrawing reactive power from the transmission line.

An important aspect in the design and implementation of an UPFC PLUS is the protection in system fault conditions. Reaction time scale of UPFC PLUS is therefore in some ms; thus, it is capable to manage active power control and corresponding reactive power compensation during short transient events like faults in the transmission system. Changes in setpoints can be enabled via communication channel which can be integrated to operator system.

The series compensation of transmission lines always distinguishes between two fault types. Internal faults are faults in the transmission line where the UPFC PLUS is connected to. External faults are all other faults that can happen outside the near environment of the UPFC PLUS. In case of any fault, the shunt converter will support the voltage at the connection point. The series converter needs to be protected against overvoltage induced by fault currents through the series transformer. Two protection mechanisms are available in the system. The series converter can be bypassed through a thyristor bypass switch in case of external fault or in addition to the thyristor bypass switch through a mechanical bypass switch in case of internal fault. External and internal fault area is explained in following Figure 7.

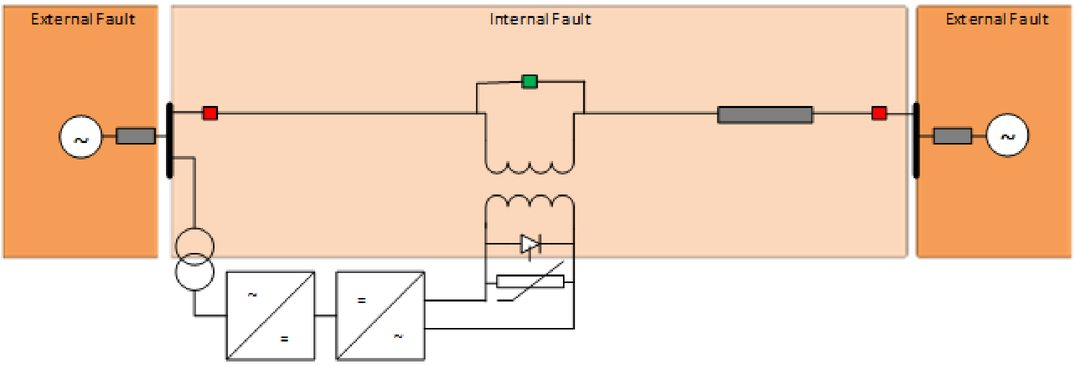

Figure 7: External and internal fault area for UPFC PLUS

Reinsertion philosophy of UPFC PLUS for external and internal faults are mentioned in Figure 8 and Figure 9 below. Dynamic performance with quick reinsertion philosophy is required to manage load flow in short transition.
In addition to the two bypass switches the UPFC PLUS is protected by a set of varistors to limit the series voltage of the transformer. The varistor is the protective measure that inherently limits the voltage in both fault scenarios. After 1 to 2 ms the Thyristor bypass will take over and short circuits the series converter which is blocked before. Once the external fault is cleared the converter will de-block and after a balancing period the Thyristor bypass will be opened and the UPFC PLUS is back in series operation.

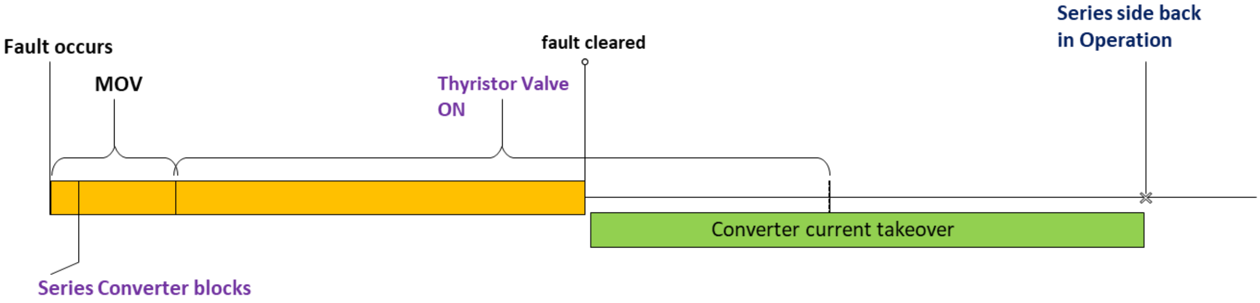

Figure 8: External fault re-insertion philosophy

Detection of an internal fault forces also the varistor to limit the inherent overvoltage across the series converter, the Thyristor bypass is closed and in additon the mechanical bypass will be closed after maximum 50 ms. The machanical bypass stays clsoed as long the fault is not cleared and the line is not re-energized. Once the line is re-energized the re-insertion procedure for the UPFC PLUS is initiated.

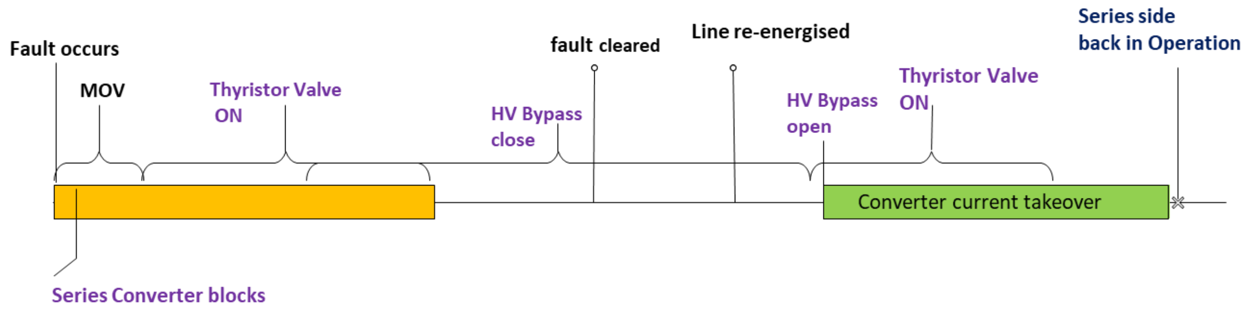

Figure 9: Internal fault re-insertion philosophy

Due to the fast and automatic re-insertion procedures the UPFC PLUS can control the load flow directly after the system fault is cleared and therefore ensures a stable operation in this fault recovery period.

5. Conclusion

Transmission grid congestion is a situation wherein the existing transmission lines are unable to accommodate all required generation and load. The ongoing change in the power generation and the generation mix challenges the existing transmission grid. In this paper we explained the possibility to tackle grid congestions via dynamic load flow management by a UPFC PLUS. The architecture of the UPFC PLUS and the integration of the system in existing transmission lines was explained. Compared to traditional power flow controllers, UPFC PLUS controls power flow in milliseconds via the series converter which also actively damp oscillations. Additionally, the system provides reactive power compensation via the shunt converter and has protection measures and automated re-insertion procedures included. Summarizing the UPFC PLUS enables

- An extended utilization of the existing grid capacity and minimizing redispatch costs.
- Maintaining grid stability by dynamic series and shunt compensation

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