

## HVDC LIGHT and FACTS Technology: A Modern Approach to Power System Interconnections

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### Abstract

The deregulation of the electricity market together with increasing constraints resulting from social opposition to the installation of new facilities puts new demands on the operators of transmission and distribution systems. These new trends enhance the need for flexibility, power quality and increased availability of transmission and distribution systems by using tools which can be implemented with limited investments, short delivery times and short planning and decision making horizons. The paper discusses HVDC Light, a new DC transmission system technology, still consisting of well-known configurations forming the system. HVDC Light is very suitable for DC power transmission for a number of applications as will be highlighted in the paper. It also highlights comparison between Conventional HVDC and HVDC Light. The paper also discuss FACTS (Flexible AC Transmission Systems), a term denoting a whole family of concept sand devices for improved use and flexibility of power systems. This paper will treat benefits of FACTS devices applied in power systems such as increased power transmission capability, improved static and dynamic stability, an increase of a availability and a decrease of transmission losses.

*Keywords-* HVDC, HVDC Light, FACTS Technologies, STATCOM, SVC, UPFC, VSC.

### 1. Introduction

Innovative solutions with HVDC and FACTS have the potential to cope with the new challenges [1,2]. By means of Power Electronics, they provide features which are necessary to avoid technical problems in the power systems, they increase the transmission capacity and system stability very efficiently and help prevent cascading disturbances. HVDC light is high voltage direct current transmission system based on solid state voltage source technology utilizes most advanced power electronics and semiconductors [3]. Power is transmitted via underground/undersea cables. More efficient way of transmitting power over distances above ~50km.

### 2. Conventional HVDC

In the second half of the last century, high power HVDC transmission technology was introduced, offering new dimensions for long distance transmission [4-6]. This development started with the transmission of power in a range of less than a hundred MW and was continuously increased. Transmission ratings of 3 GW over large distances with only one bipolar DC line are state-of-the-art in many grids today. World's first 800 kV DC project in China has a transmission rating of 5 GW and further projects with 6 - 7 GW or even higher are at the planning stage.

In general, for transmission distances above 600 km, DC transmission is more economical than AC transmission ( $\geq 1000$  MW). Power transmission of up to 600 - 800 MW over distances of about 300 km has already been achieved with submarine cables, and cable transmission lengths of up to approx. 1,000 km are at the planning stage. Due to these developments, HVDC became a mature and reliable technology.

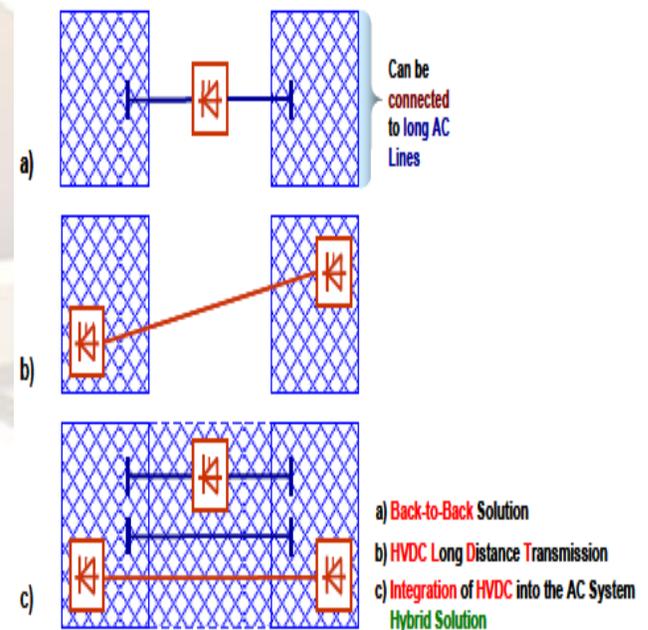


Fig.1: HVDC Interconnections

During the development of HVDC, different kinds of applications were carried out. They are shown schematically in Fig. 1. The first commercial applications were cable transmissions, for AC cable transmission over more than 80-120 km is technically not feasible due to reactive power limitations. Then, long distance HVDC transmissions with overhead lines were built as they are more economical than transmissions with AC lines [5]. To interconnect systems operating at different frequencies, Back-to-Back (B2B) schemes were applied. B2B converters can also be connected to long AC lines (Fig. 1a). A further application of HVDC transmission which is highly important for the future is its integration into the complex interconnected AC system (Fig. 1c). The reasons for these hybrid solutions are basically lower transmission costs as well as the possibility of bypassing heavily loaded AC systems.

HVDC VSC is the preferred technology for interconnecting islanded grids, such as offshore wind farms, to the power system [7]. This technology provides the “Black-Start” feature by means of self-commutated voltage-sourced converters [8].

**HVDC – High-Voltage DC Transmission: It makes P flow**

- HVDC “Classic” with 500 kV – up to 4,000 MW
- HVDC “Bulk” with 800 kV – for 5,000 MW up to 7,200 MW
- HVDC VSC (Voltage-Sourced Converter)
- HVDC can be combined with FACTS
- V-Control included

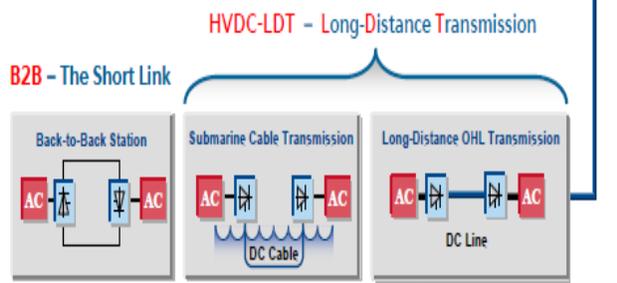


Fig.2: Typical configurations of HVDC

Voltage-sourced converters do not need any “driving” system voltage; they can build up a 3-phase AC voltage via the DC voltage at the cable end, supplied from the converter at the main grid. Siemens uses an innovative Modular Multilevel Converter (MMC) technology for HVDC VSC with low switching frequencies, referred to as HVDC PLUS [6-8].

**3. HVDC Light**

HVDC Light is the newly developed HVDC transmission technology, which is based on extruded DC cables and voltage source converters consisting of Insulated Gate Bipolar Transistors (IGBT’s) with high switching frequency. It is a high voltage, direct current transmission Technology i.e., Transmission up to 330MW and for DC voltage in the ± 150kV range. Under more strict environmental and economical constraints due to the deregulation, the HVDC Light provides the most promising solution to power transmission and distribution [3]. The new system results in many application opportunities and new applications in turn bring up new issues of concern. One of the most concerned issues from customers is the contribution of HVDC Light to short circuit currents [3]. The main reason for being interested in this issue is that the contribution of the HVDC Light to short circuit currents may have some significant impact on the ratings for the circuit breakers in the existing AC systems. This paper presents a comprehensive investigation on one of the concerned issues, which is the contribution of HVDC Light to short circuit currents.

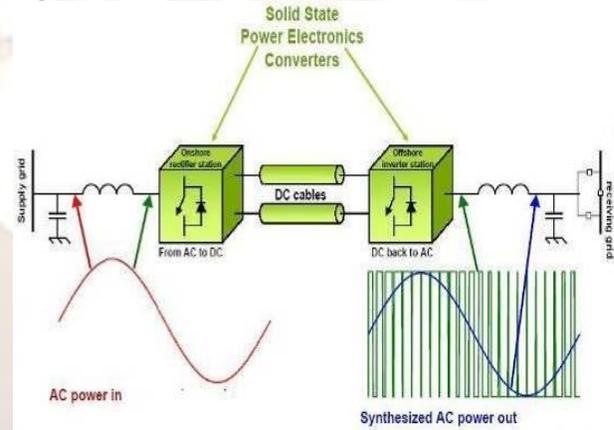


Fig.3: HVDC Light Installations

**4. HVDC Light configuration**

**4.1 Power transformer**

The transformer is an ordinary single phase or three phase with a tap changer on the secondary side. The filter bus voltage will be controlled with the tap changer to achieve the maximum active and reactive power from the converter. The current in the transformer winding contains hardly any harmonics and is not exposed to any dc voltage. The transformer may be provided with a tertiary winding to feed the station auxiliary power system.

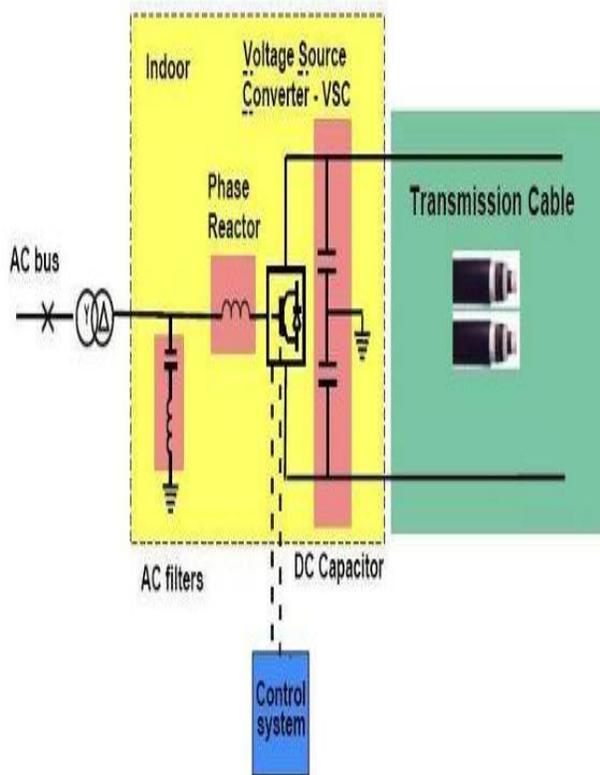


Fig.4: HVDC light converter station

#### 4.2 Converter reactors

The main purposes of the converter reactors are:

- To provide low-pass filtering of the PWM pattern to give the desired fundamental frequency voltage
- To provide active and reactive power control
- To limit the short circuit currents

#### 4.3 DC capacitors

- The primary objective of the valve dc side capacitor is to provide a low inductance path for the turned off current and also to serve as an energy store
- It reduces the harmonic ripple on the direct voltage
- The ability to limit the dc voltage variations caused by the disturbances in the system depends on the size of the dc side capacitor.

#### 4.4 The DryQ design

The DC capacitor is a DryQ capacitor which has:

- Twice the capacity in half the volume,
- Corrosion-free plastic housing,
- Low inductance,
- Shortened production time and simplified installation.

#### 4.5 AC filters

Conventional HVDC converters always have a demand for reactive power. At normal operation, a converter consumes reactive power in an amount that corresponds to approximately 50 % of the transmitted active power. The least costly way to generate reactive power is in shunt connected capacitor banks. Some of these capacitor banks can then be combined with reactors and resistors to form filters providing low impedance paths for the harmonics in order to limit them from entering into the connected AC network.

#### 4.6 Valves-The IGBT position

IGBT is the semiconductor used in HVDC light To increase the power handling, six IGBT chips and three diode chips are connected in parallel in a sub-module The IGBT has two, four or six sub-modules, which determine the current rating of the IGBT A complete IGBT position consists of an IGBT, a gate unit, a voltage divider and a water cooled heat sink. The gate driving electronics control the gate voltage and current during turn on and turn off. The voltage across the IGBT is measured and the information is sent to the valve control unit through an optical fiber The voltage divider connected across the IGBT provides the current needed to drive the gate. The functions of Valve are as follows;

- To switch voltages higher than the rated voltage of one IGBT, several positions are connected in series in each valve.
- Each IGBT position can be individually regulated in the valve to the correct voltage level.
- The flexibility of the IGBT makes it possible to block the current immediately if a short circuit is detected.

#### 4.7 Valve cooling system

It consists of water cooled heat sinks which provides high efficiency cooling. The water is circulating through the heat sink in close contact with each IGBT, which efficiently transports the heat away from the semiconductor. The water passes continuously through a de-ionizing system to keep the conductivity of the water low.

#### 5. VSC technology based on PWM

In the VSC based HVDC transmission schemes described herein, the switching of the IGBT valves follows a pulse width modulation (PWM) pattern [7,8]. This switching control allows simultaneous adjustment of the amplitude and phase angle of the converter AC output voltage with constant dc voltage even with a two-level converter. With these two independent control variables, separate active and

reactive power control loops can be used for regulation.

If  $U_C$  is in phase lag, the active power flows from ac to dc side(rectifier)

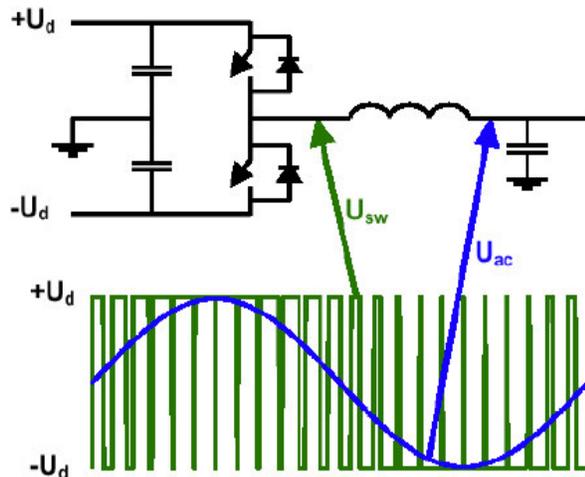


Fig.5 :VSC technology based on PWM

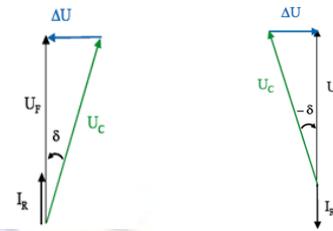


Fig.7 : Phasor representation of  $U_C \sim U_F$

If  $U_C$  is in phase lead, the active power flows from dc to ac side.

### 6. Control of Active and Reactive power

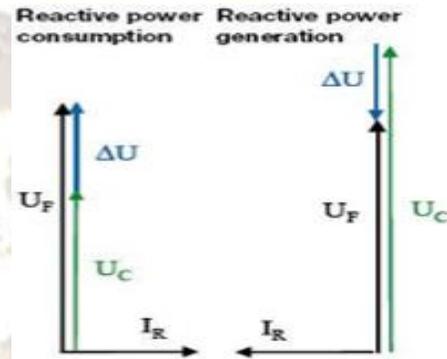


Fig.8 : Phasor representation of Reactive Power Generation & Consumption

If  $U_F > U_C$ , there is reactive power consumption.  
 If  $U_C > U_F$ , there is reactive power generation.

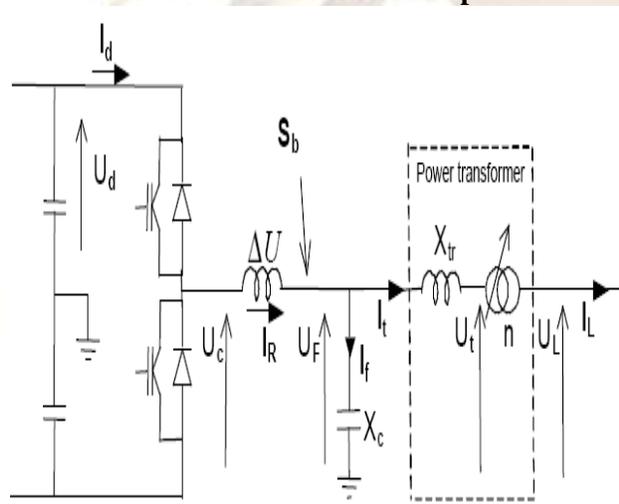


Fig.6 : VSC fed HVDC

The fundamental base apparent power at the filter bus between the Converter reactor and the ac filter is L:

$$S_b = P + j Q = \sqrt{3} \cdot U_F I_R \dots\dots\dots (1)$$

The active and reactive components are

$$P = \frac{U_F U_C \sin \delta}{\omega L} \dots\dots\dots (2)$$

$$Q = \frac{U_F (U_F - U_C) \cos \delta}{\omega L} \dots\dots\dots (3)$$

### 7. HVDC Light Cables

HVDC light cables are installed close in bipolar pairs with anti parallel currents and thus eliminating the magnetic fields. They have no technical limitation for distance as in ac cables Its strength and flexibility makes it well suited for several installation conditions They are used for control of active and reactive power. The cable system is complete with cables, accessories and installation services. The cables are operated in bipolar mode, one cable with positive polarity and one cable with negative polarity. The cables have polymeric insulating material, which is very strong and robust. This strength and flexibility make the HVDC Light cables perfect for severe installation conditions:

- The submarine cables can be laid in deeper waters and on rough bottoms.
- The land cables can be installed less costly with ploughing technique.

HVDC cables can now also go overhead with aerial cables

**7.1 Advantages of HVDC Light cables**

**7.1.1 Reliability and Quality**

To assure high reliability and availability, the HVDC light principles include simple station design, use of components with proven high reliability, automatic supervision, use of back up control systems and equipment such as measurements, pumps etc.

**7.1.2 Maintainability**

It includes quality assurance/standards, converter control, current control, current order control, PQU order control.

**7.1.3 Protective actions and effects**

It includes transient current limiter, permanent blocking, AC circuit breaker trip, set lockout of the ac circuit breaker, pole isolation, start breaker failure protection.

**Table-1: Comparison between HVDC & HVDC Light**

Conventional HVDC	HVDC light
Thyristor valve	IGBT valves
Converter transformer connects connection valve and AC grid.	Series reactor and transformer connects connection valve and AC grid.
50% filtering and reactive compensation in filters and shunt capacitor.	Only small filters are required for filtering and reactive power compensation.
Dc current smoothing by smoothing reactor and DC filter.	Dc current smoothing by DC capacitors.

**8. Features of HVDC Light**

- Independent control of active and reactive power
- Independent power transfer and power quality control
- Power reversal
- Reduced power losses in connected ac systems
- Increased transfer capacity in the existing system
- Fast restoration after blackouts
- Flexibility in design
- No relevant magnetic fields
- Low environmental impact
- Indoor design
- Short time schedule

**9. Applications of HVDC Light**

- Connecting wind farms
- Underground power links
- Powering islands
- Oil & gas offshore platforms; power from shore
- Asynchronous grid connection
- City centre in-feed
- Wind power generation
- Multi terminal dc grid
- Interconnecting networks
- Islanded operation
- City infeed

**10. FACTS Technology**

Flexible Alternating Current Transmission System (FACTS) is a static equipment used for the AC transmission of electrical energy [9, 10]. It is meant to enhance controllability and increase power transfer capability. It is generally a power electronics based device. The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems [11, 12]. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents.

The FACTS devices can be divided in three groups, dependent on their switching technology: mechanically switched (such as phase shifting transformers), thyristor switched or fast switched, using IGBTs. While some types of FACTS, such as the phase shifting transformer (PST) and the static VAR compensator (SVC) are already well known and used in power systems, new developments in power electronics and control have extended the application range of FACTS. Furthermore, intermittent renewable energy sources and increasing international power flows provide new applications for FACTS. The additional flexibility and controllability of FACTS allow to mitigate the problems associated with the unreliable of supply issues of renewable. SVCs and STATCOM devices are well suited to provide ancillary services (such as voltage control) to the grid and fault rid through capabilities which standard wind farms cannot provide Furthermore, FACTS reduce oscillations in the grid, which is especially interesting when dealing with the stochastic behavior of renewable

**FACTS – Flexible AC Transmission Systems: Support of Power Flow**

- SVC – Static Var Compensator (The Standard of Shunt Compensation)
- STATCOM – Static Synchr. Compensator, with VSC
- FSC – Fixed Series Compensation
- TCSC – Thyristor Controlled Series Compensation
- TPSC – Thyristor Protected Series Compensation
- UPFC – Unified Power Flow Controller (with VSC)

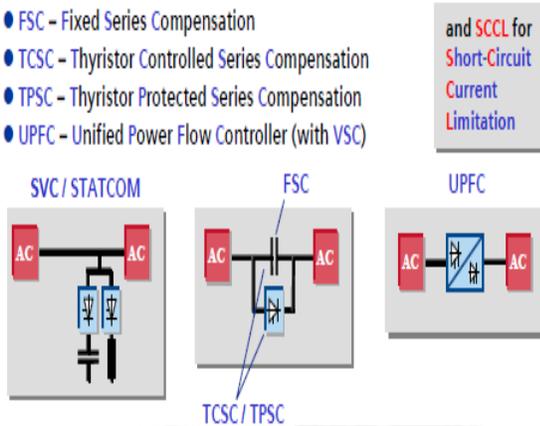


Fig.10 : Basic configurations of FACTS.

**11. Conclusion**

The stepwise interconnection of a number of grids by using AC lines, DC Back-to-Back systems, DC long distance transmissions and FACTS helps for strengthening the AC lines. These integrated hybrid AC/DC systems provide significant advantages in terms of technology, economics as well as system security [13-16]. The HVDC Light transmission system has an opportunity to transmit small scale power to long distances via cable with an opportunity to connect the passive load, separate control of active and reactive power, without any contribution to short circuit currents. This System when implemented in the power system will minimize transmission loses with optimum system security for economic operation.

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