HVDCLINK

(HVDC links for marine energy evacuation: future solutions)

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INDEX

1. General information

1 – General information

- Project general objective
  - To make progress in the research of links for **High Voltage Direct Current transmission** (HVDC) so that Basque companies of the field of energy (electrical and electronics manufacturers) are able to be in a good position in the **new scenario** with the **massive deployment of offshore wind farms**.
- Consortium
  - Leader TECNALIA
  - UPV. Grupo GISEL Grupo de Ingeniería Eléctrica
  - ORMAZABAL Corporate Technology, A.I.E
  - ARTECHE Centro de Tecnología, A.I.E

1 – General information

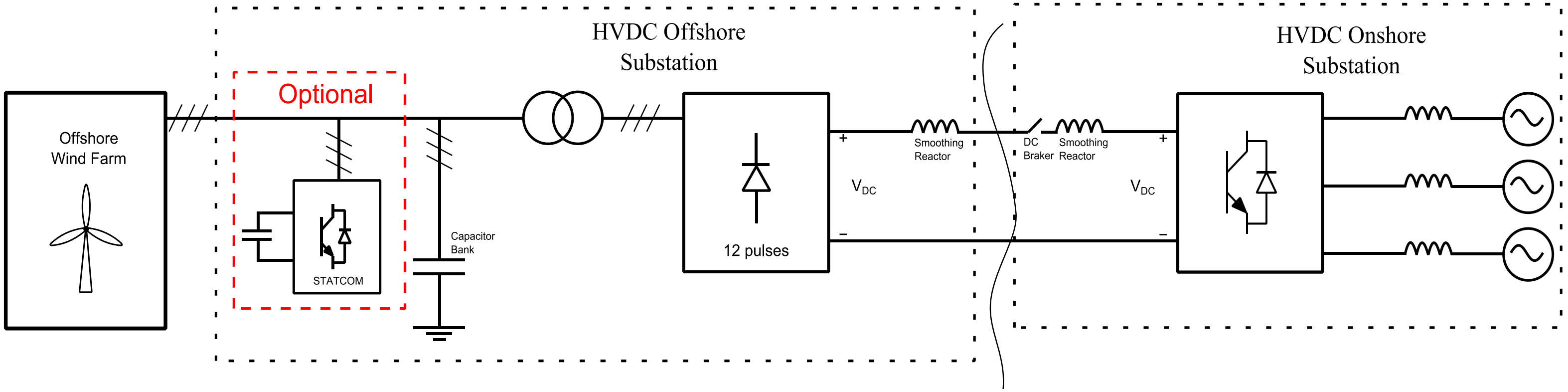
- **Budget and duration**
  - 2015 - 2017
  - 1,3 M€ (Financed by the Basque Government)
- **Research lines**
  - Hybrid HVDC transmission architecture
  - HVDC Laboratory
  - High-level control of VSC-HVDC converter stations for grid support
  - Current and voltage measurement in HVDC systems
  - Circuit breakers based on superconducting materials

2. Hybrid HVDC transmission architecture

Hybrid HVDC transmission architecture

- OBJECTIVE

Development of a new HVDC hybrid system optimized for the transmission of energy generated in offshore generation plants. The new transmission system consists of a **diode rectifier**, **a STATCOM in the offshore substation** (in the most general case) and a **VSC MMC converter in the onshore substation**.



Proposed link LCC (diode rectifier) - VSC with VSC STATCOM

Hybrid HVDC transmission architecture

- ☑ **Lower complexity** than offshore substations based on MMC converters
- ☑ **Lower size** and **weight** of the offshore substation
- ☑ **Higher efficiency** and **reliability**
- ☑ **Lower cost** (substation and development)
- ☒ **Lower flexibility** and control (change in the direction of energy flow, reactive power, disturbances ..)
- ☒ The **AC** collector **voltage**, amplitude and frequency, must be controlled for correct operation. **Radical change** in the **control** philosophy of **wind turbines unless** a **STATCOM** is **used**

Hybrid HVDC transmission architecture

- TASKS

1. Analysis of feasibility and dimensioning of the elements that make up the **transmission architecture**

   - Power of the link: 500 MW
   - Voltage of the offshore wind farm AC grid: 33 kV
   - AC offshore substation: 33 kV – 220 kV
   - Voltage of AC transmission cable (AC collector): 220 kV
   - DC offshore substation (12 pulse rectifier). DC bus voltage: +/-320 kV
   - Power of STATCOM: 100 MW
   - AC Voltage of STATCOM 33 kV. Transformer for STATCOM: 33 kV – 220 kV
   - Reactive power of capacitive elements: 100 MW

Hybrid HVDC transmission architecture

2. Development of algorithms to control the **AC collector voltage**
   - **Centralized** solution: Voltage control using a **STATCOM**
   - **Distributed** solution: Voltage control using the **wind turbine converters**
3. Development of control algorithms of **VSC MMC** located in the **onshore** substation
   - Nominal power: 500 MW
   - Onshore AC voltage: 220 kV
   - Selected topology: MMC converter with 320 sub-modules per arm
   - Modulation strategy: staircase modulation
   - Low level controllers: Circulating current and balancing algorithm
   - High level control: Vdc-Q with droop characteristics

Hybrid HVDC transmission architecture

4. Development of the **model** with the **proposed** transmission **architecture**
   - **Complete model**: Wind turbines, AC offshore grid, rectifier, STATCOM (optional), DC transmission line, MMC inverter (onshore) and AC grid (onshore)
5. **Validation** of the proposed architecture and developed control algorithms under **normal** and **disturbed** operating conditions

Hybrid HVDC transmission architecture

- NEXT STEPS: **Experimental validation** of developed concept

1. SHORT TERM: The developed **control algorithms** and the **HVDC laboratory** (described in section 3) will be **integrated**

   The proposed **transmission architecture** and the method to **regulate** the **AC grid voltage** will be **validated**

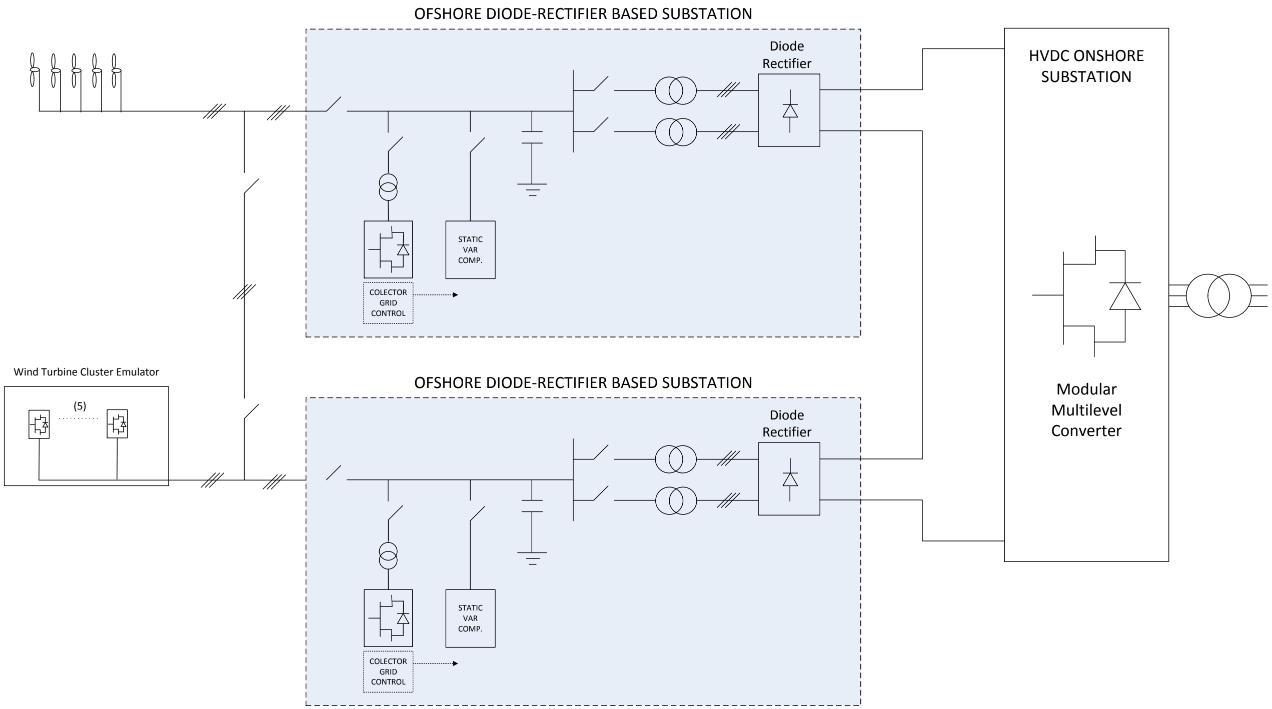
2. MEDIUM TERM: If any **manufacturer** shows **interest** in this **solution**, the next step (in collaboration with them) is to **demonstrate** the **feasibility** of the architecture in a **Laboratory** of a **relevant power**

3. HVDC Laboratory

HVDC Laboratory

- OBJECTIVE

To own an **HVDC laboratory** with the **hybrid architecture** to be developed



HVDC laboratory layout with hybrid transport architecture

HVDC Laboratory

The figure shows the complete laboratory, which includes two offshore substations with diode rectifier and STATCOM for two wind farms. In the onshore substation an MMC converter is located connected to the grid.

In the first phase of construction of the laboratory, we will focus on developing one diode rectifier substation, a STATCOM, and the emulator of a wind turbine cluster.

With these key elements we will make a first experimental validation of hybrid transport technology. The power level is 100kW, significant enough to draw reliable conclusions.

- ACTUAL STATUS

Under development. By the end of 2017 will be operative

4. High-level control of VSC-HVDC converter stations for grid support

- OBJECTIVE

To analyze the **interaction between VSC-HVDC converters** and the **AC system**, for different phenomena related to power quality and voltage and frequency control.

- TASKS

1. To analyze the **influence of VSC-HVDC converters** on the **AC grid power quality**

   - Conclusions:

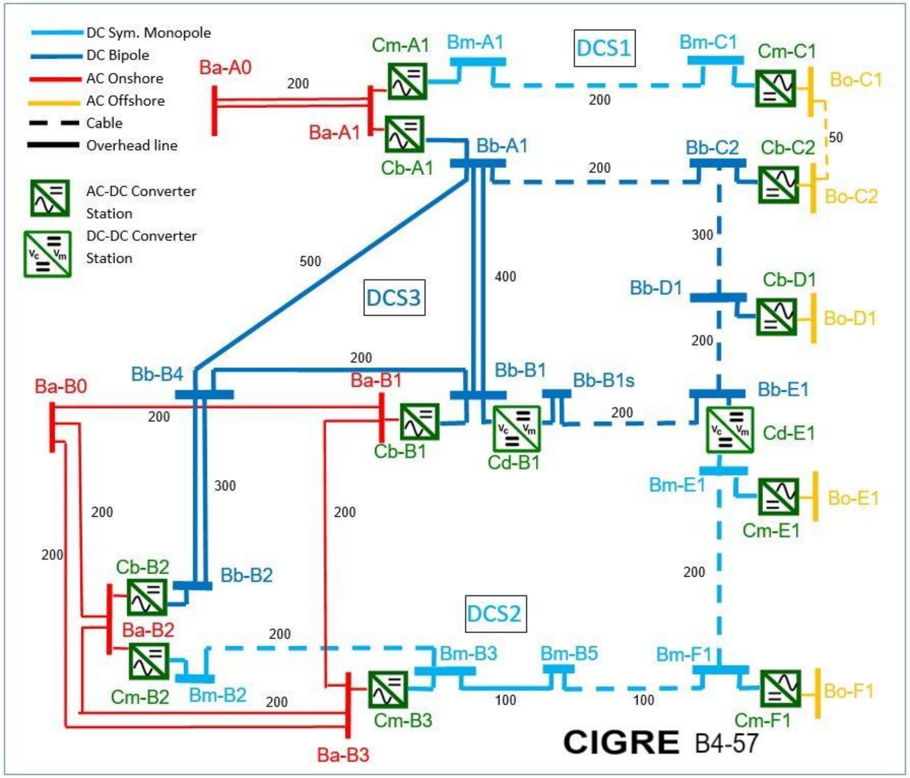
     - Voltage harmonics on the AC side of the VSC converters depend on their design and configuration
     - Current harmonics depend on the voltage harmonics, on the impedance-frequency characteristic of the AC system at the connection point and on the harmonic impedance of the substation VSC
     - Multi-level VSC converters: lower harmonic voltage distortion than two-level converters but resonance phenomena or harmonic amplification may appear in the grid connection
     - Reduction in the emission of the usual harmonics (low order odd harmonics) linked to the increase in the emission of supra-harmonics (from 2 to 150 kHz)

2. **Influence** of VSC-HVDC converters **on system operation**
   - Tasks:
     - Analysis of grid codes for HVDC systems: ENTSO-E, UK, Germany.
     - Implementation of control algorithms to comply with the grid codes (P, f, Q-V control)
     - Control algorithms for enhancement of interaction AC-DC (Power and sub-synchronous oscillations, Fault Ride-Through in balanced and unbalanced faults)

3. Development of AC grid models

➢ CIGRE test grid (AC / DC mixed) and generic AC grid models for study of:

- Voltage and frequency variations
- Unbalanced voltages
- Fault ride-through
- Sub-synchronous oscillations
- Harmonic Distortion



High-level control of VSC-HVDC converter stations for grid support

- ACTUAL STATUS:

1. Analysis of **grid codes for HVDC systems**: ENTSO-E, UK, Germany
2. Implementation and validation of generic AC grid models
3. Implementation and **validation of control algorithms** to comply with the grid codes, implemented **in HVDC converters**: controls of active and reactive power, voltage, frequency and balanced and unbalanced voltage dips

High-level control of VSC-HVDC converter stations for grid support

- NEXT STEPS:

1. **Validation of high-level control algorithms** for AC grids, implemented in HVDC converters: **power oscillation damping and subsynchronous oscillations**
2. **Analysis of harmonics of wind farms** connected to the AC grid through VSC-HVDC stations

5. Current and voltage measurement in HVDC systems

Current and voltage measurement in HVDC systems

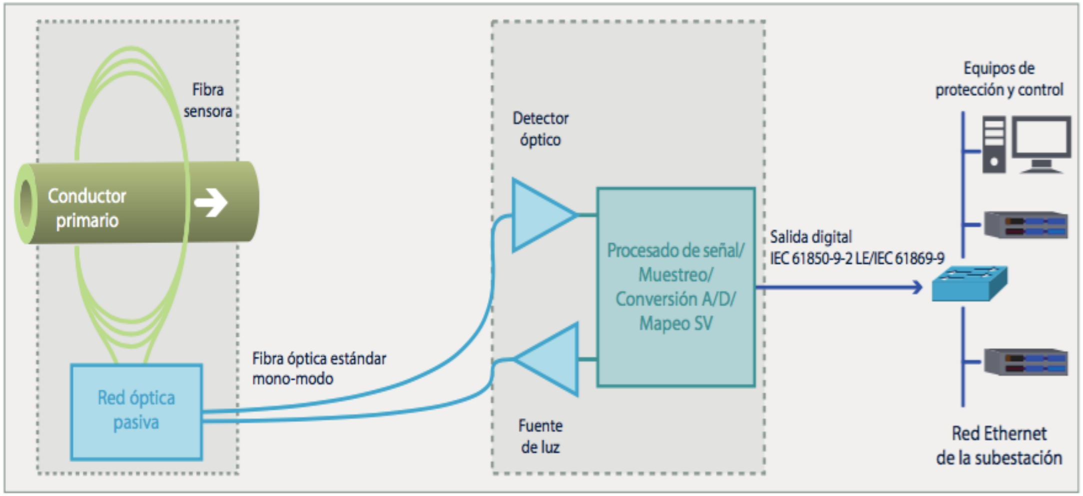
- OBJECTIVE

To design two sensors, one optical for current and one R-C divider for voltage, to provide digital **measurements for HVDC lines**. As they are oriented to direct current circuits, they do not exploit the principle of electromagnetic induction that forms the basis of conventional transformers.

- VOLTAGE MEASUREMENT
  - **R-C divider**
  - Concept similar to high voltage capacitive voltage transformer
  - For HVDC, replacement of the medium voltage inductive electromagnetic unit by an electronic unit in charge of the digitization of the outputs

Current and voltage measurement in HVDC systems

- CURRENT MEASUREMENT
  - Composed by:
    - The current sensor itself, consisting of an optical fiber which surrounds the conductor through which the current flows
    - A polymeric insulator integrated with single-mode optical fibers
    - A terminal electronic unit, also called concentrator, located in the control house



Optical current sensor: block diagram

Current and voltage measurement in HVDC systems

- Operating principle **based on the magneto-optical Faraday** effect
- The **concentrator** unit includes **a laser light source** and the digital output interface compatible with the protocols defined in the international standards IEC 61850-9-2 and IEC 61869-9.

ACTUAL STATUS

Prototypes of both sensors have been constructed, obtaining satisfactory results in the laboratory

NEXT STEPS

Additional tests will be performed in the laboratory

6. Circuit breakers based on superconducting materials

Circuit breakers based on superconducting materials

- OBJECTIVE

Analysis of the feasibility of using switches based on superconducting materials, combined with other conventional switchgear, for the **DC current cut-off** in HVDC

The extinction of the DC faults is focused on the use of AC circuit breakers. Future **multi-terminal** grids make the use of DC switches a desirable option in this kind of systems

- TASKS

1. Analysis of **DC circuit breaker technologies** in HVDC systems and high temperature superconducting.

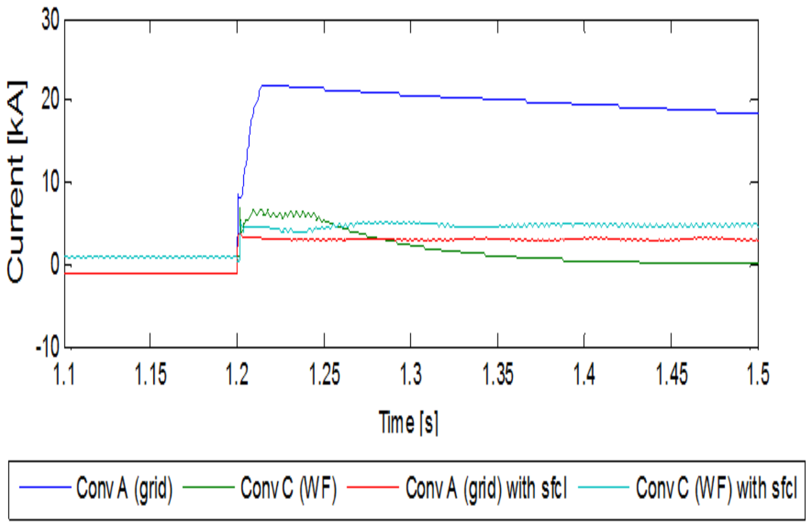
Circuit breakers based on superconducting materials

2. Analysis of superconducting fault current limiting devices (SFCLs)
   - Requirements for HVDC:
     - Minimum impedance under normal operation
     - Quick limit of current
     - Quick and automatic recover
     - Fail-safe
     - Compact and lightweight structure. Especially important for offshore platforms
     - Applicable to high DC voltages
   - SFCLs are attractive candidates for HVDC, but:
     - Ripple in DC
     - Two SFCLs for each termination
     - Cost of platform for cryogenic cooling system
     - Cost of HTS materials: BSCCO around 180$/kAm, YBCO around 400$/kAm and MgB2 around 13$/kAm.

Circuit breakers based on superconducting materials

- **Application in HVDC**: at **present** there are **only** projects in **AC**. There is no evidence of prototypes or HVDC installations with SFCLs, just theoretical studies and simulations.

3. Combination of an FCL with a conventional switch for the **DC current cut-off** in HVDC. Models and simulations.



Fault current without / with SFCL in point to point HVDC link

7. Barriers to innovation deployment

7 - Barriers to innovation deployment

- Very expensive systems
  - Difficult to increase the power in demonstrators
- Technology well controlled by a few manufacturers. As they want to protect their technology:
  - Difficult to work with them
  - Few information for the utilities
- Hybrid architecture: radical change in the control philosophy of wind turbines unless a STATCOM is used.
- Legal framework: not very developed, but working on it

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