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Stability and interaction analysis in islanded power systems including VSC-HVDC and LCC-HVDC power converters

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SUMMARY

Islanded power systems are often connected to larger mainland power systems using HVDC cables. These interconnections are used to import power at lower cost compared to local generation and improve the security of supply. The increase of HVDC interconnectors in islanded systems will allow the reduction of local synchronous generation, which might lead to new interaction and stability problems due to the low inertia and short-circuit power available in the system. Traditionally LCC-HVDC technology has been used to connect island grids, but recently VSCs are presented as an alternative solution that offers more controllability to the islanded grid. Therefore, in order to increase the power transfer to the islands multi-infeed hybrid HVSC systems with VSCs and LCCs might become a common solution. The introduction of VSCs in islanded systems will allow operations in weak grids, but possible interactions with LCCs must be analysed in detail. This paper introduces the potential interactions in multi-infeed HVDC systems with LCCs and VSCs. An initial benchmark model of an islanded power system with a LCC and a VSC-HVDC link is presented to analyse new interaction phenomena between the converters and the islanded AC grid. Simulation results in PSCAD/EMTDC are presented to validate the benchmark model for voltage stability and commutation failure analysis.

KEYWORDS

Multi-infeed HVDC systems, LCC-HVDC, VSC-HVDC, islanded systems, weak grids, interactions

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INTRODUCTION

The increasing number of High Voltage Direct Current (HVDC) transmission systems has brought more power electronics devices connected to the grid, leading to areas with high density of power converters, i.e. in Northern Europe, where HVDC is used to interconnect different countries and also offshore wind power plants. The presence of such an amount of power electronic devices can lead to operational issues caused by interactions between the power converters and also with other elements of the grid [1]–[5].

These interactions are more significant in small isolated systems, i.e. islands connected to the mainland through HVDC links. Interconnecting islands to mainland has been a solution to reduce the high costs of local generation and improve the security of supply. Existing relevant examples of this HVDC application are: Gotland, connected to the Swedish main grid [6], Jeju island, connected to the Korean peninsula through two LCC-HVDC links [7], Majorca, connected to the Iberian peninsula through a LCC-HVDC link [8], Sardinia and Corsica, connected to the Italian peninsula by means of a 3-terminal LCC-HVDC system [9] and Zhousand islands, connected to the Chinese main grid through a 5-terminal VSC-HVDC system [10]. In the case of Gotland and Jeju, the HVDC systems were designed to supply the whole demand of the island [11], [12]. While most of these projects were based on Line Commutated Converter (LCC) technology, recent projects are considering the option of Voltage Source Converters (VSC) technology, which can provide additional benefits for the island power system [13].

The proliferation of new HVDC interconnectors in islanded systems might lead to a reduction of the conventional synchronous generation-based power plants connected to the grid, with the associated decrease of inertia and short-circuit current capacity in the resulting system. This will define new challenges on the system stability and the response during system faults. In these islanded systems with high penetration of power electronics, power system dynamics heavily depend on the converter operation and control, which requires new methodologies to study the system stability and the potential interactions between components.

This paper presents potential challenges in the operation of islanded systems with LCC and VSC-HVDC links in terms of stability and interactions. Also, a simulation model in PSCAD/EMTDC has been implemented to analyse interactions between HVDC converters and other elements of an islanded grid.

OPERATION OF ISLANDED SYSTEM WITH VSC AND LCC-HVDC LINKS

Operation of multi-infeed HVDC systems with LCC have been extensively studied in the literature [14]–[16]. Five main interactions were identified: transient overvoltage, commutation failure, harmonic interaction, power voltage stability and control interactions [15]. Also, mitigation strategies based on converter design and control coordination were proposed to limit the impact of these interactions [15]. In case of weak systems with low inertia, e.g. small islands, frequency stability may also be considered [16].

Multi-infeed HVDC systems with LCC and VSC-HVDC links could become more common, which brings more complexity to the system operation. An example of dual-infeed HVDC system is represented in Figure 1, where an island (AC grid 1) is connected to the mainland (AC grid 2) by one LCC-HVDC link and a VSC-HVDC one. Gotland is the first island with LCC and VSC- HVDC interconnections and other islands, such as Jeju [7], are considering the introduction of additional VSC-HVDC links.

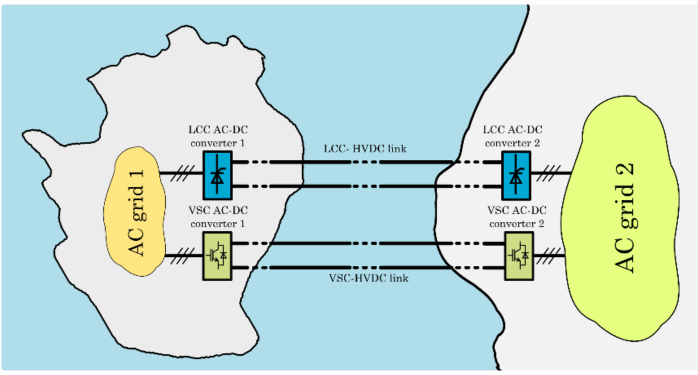

Figure 1. Example of dual-infeed HVDC system with LCC and VSC links

Multi-infeed systems based on LCC and VSC technologies can solve part of the issues previously presented for LCC-based systems. VSCs do not present commutation failure because IGBT's commutation does not depend on grid conditions. VSCs also offer higher control flexibility which can improve the stability to the grid and allow them to operate connected to weaker grids compared to LCCs. However, classical vector control may not be effective when VSCs are connected to a weak grid. Different solutions have been reported, e.g. modification in the currents reference loop was presented in [17], while [18] proposed the emulation of synchronous machine, which is known as Power Synchronization Control (PSC).

The operation of multi-infeed LCC and VSC-HVDC system will highly depend on the strength of the grid. In strong grids, the operation mode is not relevant, as the grid can maintain the converter AC bus voltage within acceptable ranges. Therefore, VSCs can work in either PQ or PV modes. When reducing the strength of the grid, VSCs may contribute to improve the system stability, operating in PV mode or providing frequency support in case of systems with low inertia. When synchronous generation is not sufficient to ensure frequency stability, VSCs could operate in grid-forming mode, i.e. generating the voltage magnitude and angle [19]. Converter grid-forming control strategies must ensure stable operation with the existing AC grids.

SYSTEM DESCRIPTION

The system under study is an islanded grid fed by a LCC and a VSC -HVDC link, that import power from a main grid. Switching models have been used for the inverter converters connected in the island, while the rectifier converters are represented as voltage sources. The islanded grid is modelled as a Thévenin equivalent, with rated voltage V_g and short-circuit impedance Z_{SC}, and two overhead lines, L1 and L2, which are represented with frequency dependent models.

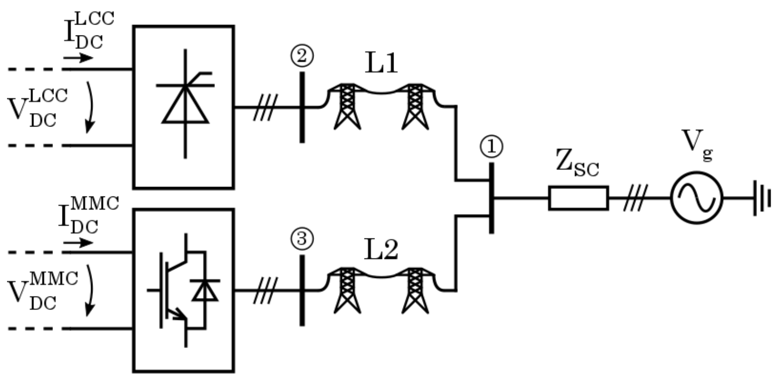

Figure 2. System under study

Configuration and control of LCC-HVDC link

The LCC-HVDC link is based on 12-pulse bridges with an asymmetrical monopole configuration. The rectifier side is represented with an average model, as shown in Figure 3, which is expressed as [20]:

$$V_{DC-r}^{LCC} = \frac{2\sqrt{2}}{\pi} T\, V_{AC2} \cos\alpha - I_{DC}^{LCC} T \frac{6}{\pi} \omega L_{AC} \tag{1}$$

where, V_{AC2} and ω are the line-to-line voltage and angular frequency of the AC grid, I_{DC}^{LCC} is the DC current through the LCC-HVDC link, T is the transformer ratio and L_{AC} is the equivalent inductance of the transformer. The inverter side, is represented with a detailed model including thyristors, transformers and reactive and harmonic compensation filters.

A conventional operation is considered, where the LCC-rectifier controls DC current and the LCC-inverter controls DC voltage[21]. An extinction angle control is also implemented in the inverter side to reduce the risk of commutation failure. The control structure is based on PI controllers, which define the firing angles for the thyristors, as shown in Figure 3.

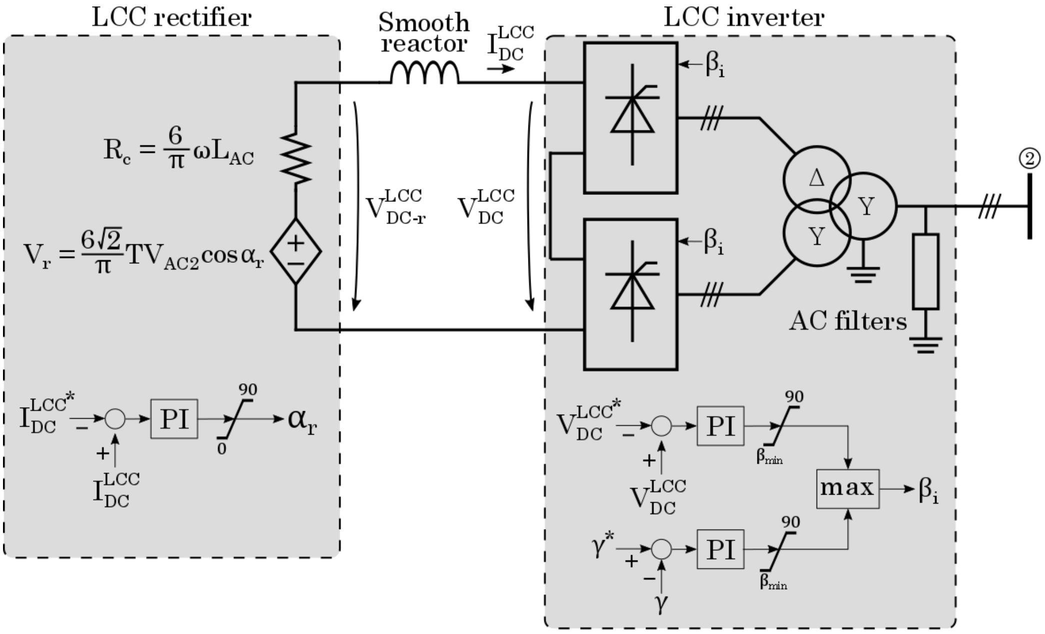

Figure 3. Configuration and control of LCC-HVDC link

Configuration and control of VSC-HVDC link

The VSC-HVDC link is based on Modular Multilevel Converters (MMC) with an asymmetrical monopole configuration. The rectifier side is modelled as a DC voltage source, as shown in Figure 4, whereas the inverter side is represented with the MMC accelerated model proposed in [22]. This MMC model represents all the submodules of the converter individually as capacitors that are connected or disconnected depending on their switching state.

The VSC-HVDC link operation considers the VSC-rectifier controlling DC voltage and the VSC-inverter controlling active power. Also, the VSC-inverter controls the AC voltage of the island system to improve operation in a weak grid. The VSC-rectifier control is not represented, whereas the VSC-inverter includes a detailed MMC control. The control strategy for the MMC is shown in Figure 4 and is based on [23]. The main objective of the MMC control is to exchange power between the AC and DC grids, while ensuring balancing of the energy stored in all the arms without large deviations. Also, Nearest Level Modulation (NLM) is used as a modulation technique, which can reduce the average commutation frequency [24].

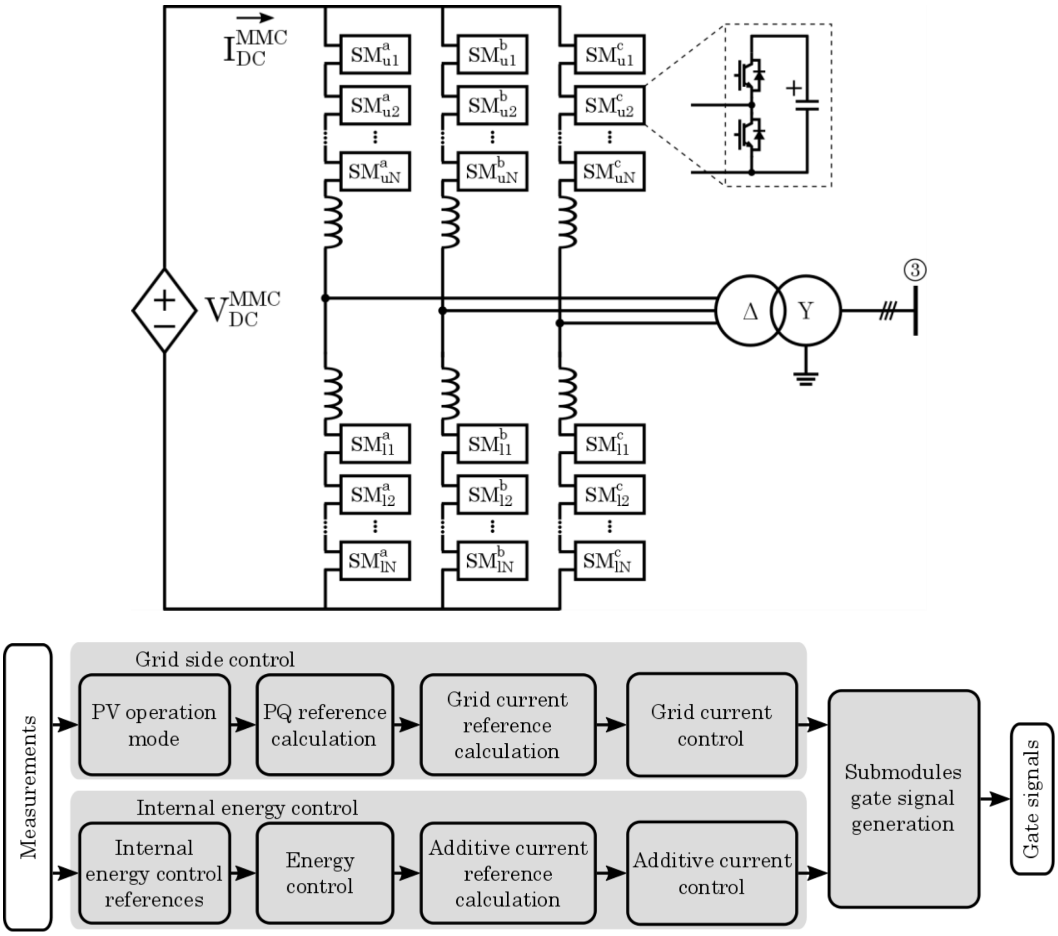

Figure 4. Configuration and control of VSC-MMC-HVDC link

CASE STUDY

The previous system has been simulated in PSCAD/EMTDC with the parameters shown in Table 1. This case study represents interactions due to a weak islanded ac grid. Two scenarios are presented to analyse the influence of the grid strength on the converter stability. In particular, two short-circuit powers of the equivalent AC grid of the island are considered: 3 GVA and 2.5 GVA.

Table 1. System parameters

Parameter	Symbol	Value	Unit
Short-circuit power of the grid at bus 1	S_{sc}	3000	MVA
AC grid voltage	V_g	220	kV
Rated active power of the LCC	P_{LCC}	200	MW
Rated active power of the MMC	P_{MMC}	500	MW
Line 1 length	$L1$	15	km
Line 2 length	$L2$	15	km

Figure 5 and Figure ***6*** show the AC voltage, active and reactive powers at the HVDC converter terminals. Initially both converters are not importing active power and the MMC controls AC voltage. At 1.5 s the LCC increases active power as a step variation up to the rated value (200 MW). Voltage variations at buses 2 and 3 are higher when the island grid is weaker, i.e. when the short-circuit power is 2.5 GVA. MMC reduces reactive power consumption to regulate the AC voltage back to 1 pu. At 2.5 s the MMC increases active power as a step variation up to the rated value (500 MW). If the short-circuit power is 3 GVA the system is stable, but the LCC active and reactive power are a disturbed as its performance is highly dependent on the AC voltage. When the short-circuit power is reduced to 2.5 GVA the voltage drop in the LCC's bus is too high, leading to commutation failure. The system is totally recovered after 200 ms. Figure 7 shows the AC currents at the LCC terminal, where two commutation failures are identified.

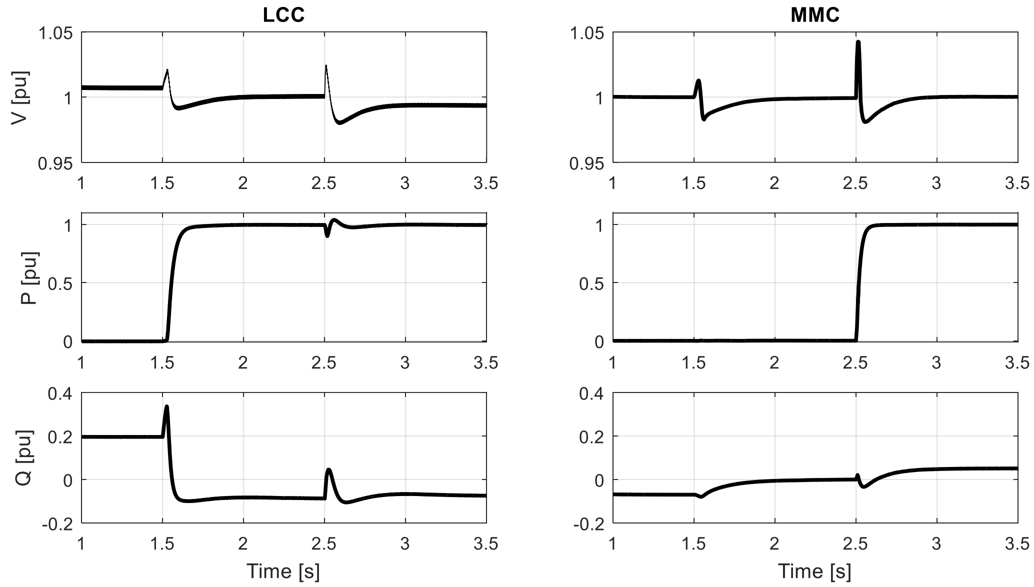

Figure 5. Simulation results ($S_{SC} = 3000$ MVA)

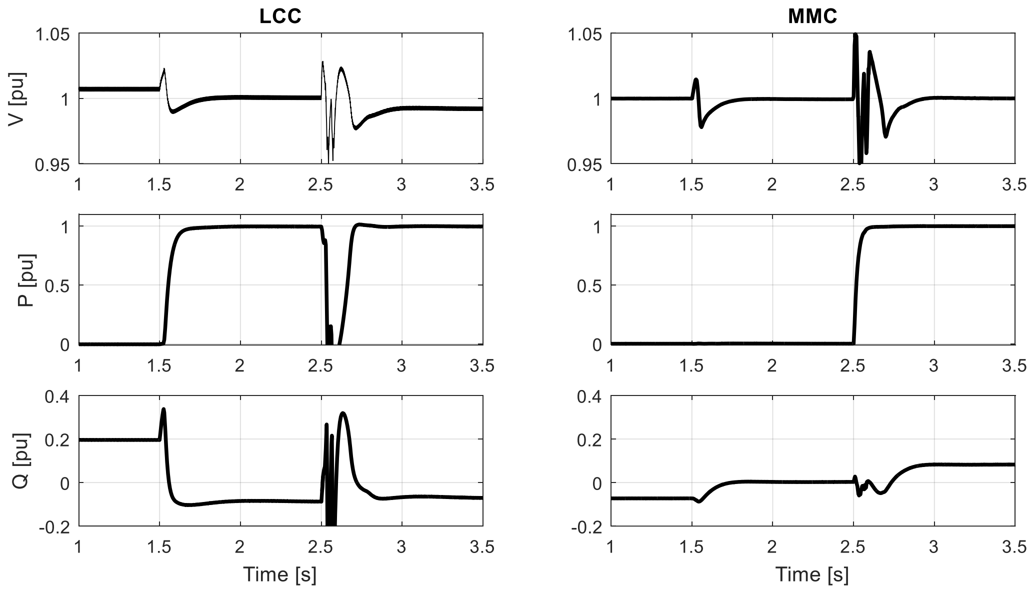

Figure 6. Simulation results ($S_{SC} = 2500$ MVA)

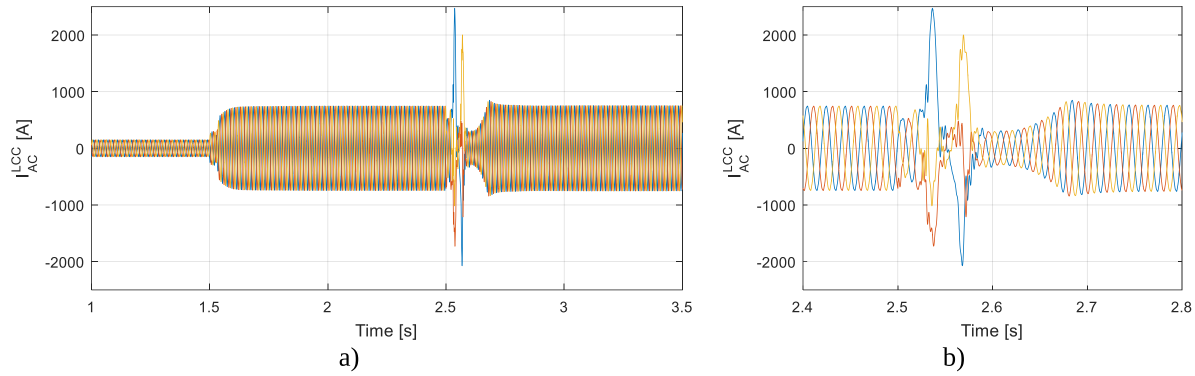

Figure 7. LCC AC current during commutation failure

CONCLUSIONS

This paper has discussed potential challenges in multi-infeed HVDC islanded system with LCC and VSC-HVDC links. Interactions between the converters due to voltage instability are expected in weak systems with low short-circuit power. Also, in weak systems with low inertia, it is important to decide when implementing grid-forming techniques. An initial case study with detailed converter models has been implemented to study the interactions due to voltage instabilities and commutation failures in islanded systems connected by LCC and VSC-HVDC links. In order to analyse scenarios where grid-forming control is required, the presented model must include a detailed representation of synchronous generation.

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