CONTROL AND PROTECTION OF A MULTITERMINAL LOW VOLTAGE DC SYSTEM BASED ON VSC

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The design process of a dc system, where DG and storage system are interconnected, requires the selection of the most suitable devices for responding to the necessities and requirements of the optimal functioning of the power system. The energy management of the proposed dc grid requires the choice of an optimal control strategy for obtaining the best performances of the system through: realization of a bidirectional flow ac-dc; insurance of a high degree of voltage quality and supply continuity; interconnection and efficient use of DG and storage systems. The fast and safe isolation of the dc fault, such that the dc distribution system equipments are not damages, is the most challenging task. The simulations demonstrate the feasibility and correct operation of the system control logic and the dc protection strategy.

Keywords: lv dc distribution system, premium power quality, dc protection.

1. Introduction

The major part of the DGs and storage systems are generating dc power or require an intermediate dc stage before power injection in a possible ac network [1], [2]. Nowadays, the customers requiring a high supply quality are installing back-up power, like uninterruptible power supply (UPS) or equipments for improving the voltage quality, like dynamic voltage restorer (DVR) and active filters: also these equipments are anyhow characterized by the presence of a dc stage [3]. Other loads, even supplied with ac power, are operating basically in dc and thus require a ca/cc conversion stage as input. A solution for ensuring a high degree of supply continuity is the design of a low voltage (lv) dc grid, where the sensitive customers are interconnected. Currently, there are installations using dc power for their operation [4]. To support this idea it is considered the successful use of the dc for transporting the electrical energy (High Voltage DC), for supplying the naval systems and electrical traction units.

Likelihood the ac distribution systems, the low voltage dc distribution system enables that several ac systems to be integrated by way of a dc network

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(off-shore wind farms, photovoltaic power sources, fuel cell systems), but also to deliver electrical energy with high power quality to sensitive customers (telecommunications centres, data management systems, electronic equipment systems). As the ac fault protection system does not represent such a difficult task, the dc circuit breaking has been covered. A protection strategy using an IGBT breaking system is used. The fast and safe isolation of the dc fault, such that the dc distribution system equipments are not damages, is the most challenging task. The simulations demonstrate the feasibility and correct operation of the system control logic and the dc protection strategy.

2. Low voltage DC distribution system layout

The main purpose of the dc distribution system is to ensure a high degree of power quality and supply reliability for the customers supplied by it. Also, the network is thought to facilitate the interconnection of the distributed generators and of the storage systems.

The layout of the dc distribution network with distributed generators, storage energy systems and ac/dc sensitive loads is illustrated in Fig. 1. As it can be seen in Fig. 1, apart the ac supply and the MV/LV transformer, are present the equipments realizing the conversion ac/dc, the power systems responsible for ensuring a high degree of the voltage quality and continuity, and the dc and/or ac loads.

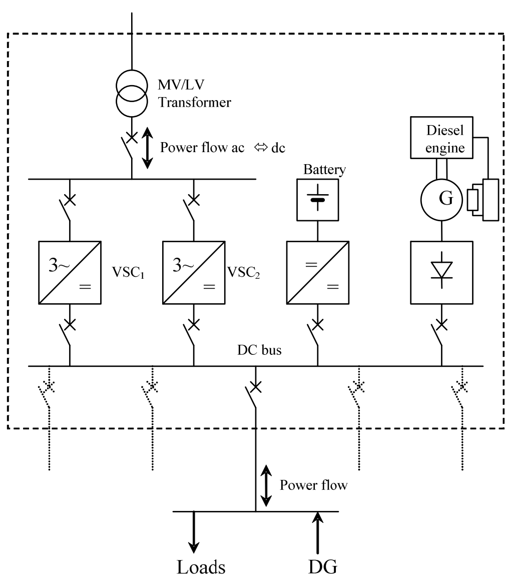

Fig. 1. Layout of the low voltage dc distribution system

The voltage source converter is a PWM current-controlled one, forcing the instantaneous phase current to follow a sinusoidal current reference template. The ac input current drawn by the converter is controlled to become a sine wave, which is in phase with the input voltage and thus the resulting input power factor is maintained at unity [5]. The use of the forced commutated converter imposes the constraint that the output dc voltage must have a higher level than the peak value of the maximum ac input voltage [6].

To guarantee the supply continuity of the customers during short-duration interruptions, a storage power system is interconnected to the low voltage dc distribution system with the help of a bidirectional chopper. Storage is requested to satisfy the power balance in case of increase of the load demand without neglecting the quality of other network quantities, such as bus voltage magnitudes. The bidirectional chopper allows the recharge of the storage system, if it is necessary, when the power is flowing from the ac network to the dc system or when in the dc network an excess energy is available. During the discharge process of the battery, the control system maintains and stabilizes the dc voltage during islanding operation of the dc network.

In Fig. 1, in the low voltage dc distribution system, distributed generators are present. This is because one of the main purposes of the dc distribution system is to allow a more easily integration of the distributed generators, some of these generating directly in dc (fuel cells, photovoltaic systems), while others requiring an intermediate dc conversion stage (micro-turbines, micro-hydro, micro-wind turbines).

3. Control logic

The utilization of the optimized control is basing on the supervision of the sources and converters states that has to determine the power requests such that to realize the load sharing. The supervisory control allows avoiding the interaction between the electric devices controllers and obviating the occurring high or sudden transients, as illustrated in Fig. 2. The input commands and the limiting values to these controllers come from the supervisory control that produces the required references for the system devices.

The rigorously established voltage thresholds are illustrated in Fig. 3. In Fig. 3 the voltage threshold V_{CONV} is maintained by the interface converter. For variations of the load demand, the control loop of the converter has to maintain the dc voltage at the threshold V_{CONV}. In case of ac faults or outage of both VSC converters, the dc voltage falls below V_{BS} determining the battery intervention. The storage system becomes predominant and regulates the dc voltage, stabilizing it to the value V_{BS}, only if the storage system is fully or partially charged.

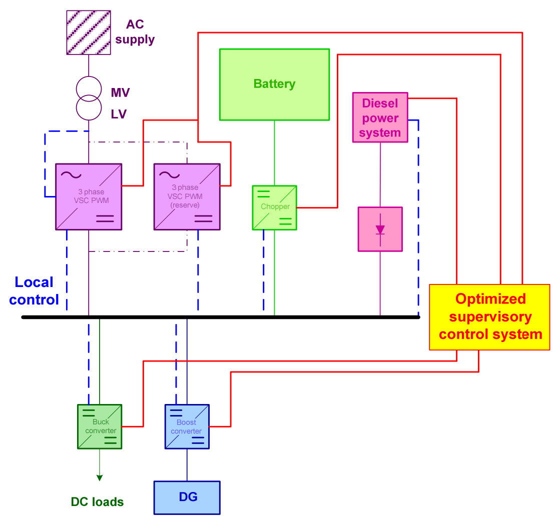

Fig. 2. Supervisory control system

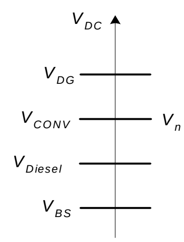

Fig. 3. Voltage thresholds assigned to the power system components

4. Interface converter

The three reference currents i_{ref} are obtained multiplying the three phase sinusoidal balanced voltages v_1, with a gain G representing the smoothed output of a proportional-integral (PI) controller used for obtaining null steady state error of the dc voltage [5], [6]. These ac voltage components will be generated by applying a conventional algorithm based on abc-dq and dq-abc Park transformations to the measured mains voltages. Therefore the key relation of the control is

$$i_{ref} = G \cdot v_1 \tag{1}$$

A control strategy that generates three sinusoidal and balanced currents even under voltage distortion or unbalance will be adopted. A modulation technique with constant commutation frequency and high accuracy and dynamics is used.

5. Case studied

The rated power of the low voltage dc system is 800kW, with a dc voltage equal to 800V. The characteristic data of the current-controlled interface converter are reported in Table 1. The dc system has been tested both for showing the correct operation of the VSC control and of the protection system [7]. The three phase ac currents absorbed by the ac/dc interface converters and flowing through the voltage source converter inductors are illustrated in Fig. 4.

Table 1

Low voltage distribution system characteristic data

P rated power	800kW
L_s VSC input inductance	0.061mH
f_{sw} switching frequency	5kHz
t time step	1μs
C_{dc} dc bus capacitance	0.2F

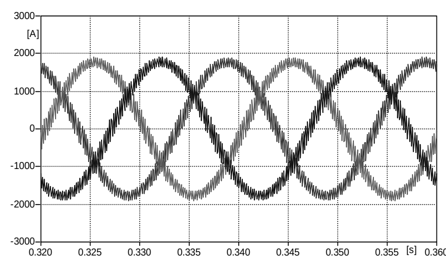

Fig. 4. AC currents flowing through converter inductors

The three phase ac currents generated are sinusoidal and in phase with the input voltage, resulting that the control technique for the ac/dc interface converter is operating efficiently.

Two electronically interrupters were used, one for each pole, controlled by an over-current relay. The choice for two interrupters is justified by the necessity to interrupt the pole-earth fault [8]. The relay measures the currents of the two poles and commands their disconnection even when one current exceeds the established threshold. This choice protects the ac/dc converter in case of unsymmetrical dc pole-earth faults. The layout of the dc system, in case of a pole-pole fault, used for the protection system investigation is illustrated in Fig. 5. The dc power system has a rated power of 800 kW, thus resulting a line current of 1000 A in case of a 800 V dc bus voltage. Hence, the instantaneous over-current protection threshold was set to 2000 A, twice the rated current. The current, in case of a fault occurring at time instant t = 0.25 s, is illustrated in Fig. 6. The fault occurs nearest the dc capacitors installed across the dc bus of the VSC, resulting in a current is high spikes due to the contribution of these capacitors in the first instants after the fault occurrence. The currents spread further away and experience a transient process with high-frequency oscillations between the dc capacitors and the line inductance (established at 1μH). The waveform of the dc voltages upstream the IGBT breaking system are illustrated in Fig. 7. Initially, the dc voltages drops due to the dc fault, but slowly and much less with respect to the one of the dc bus due to the effect of the decoupling inductance present within the IGBT breaking system.

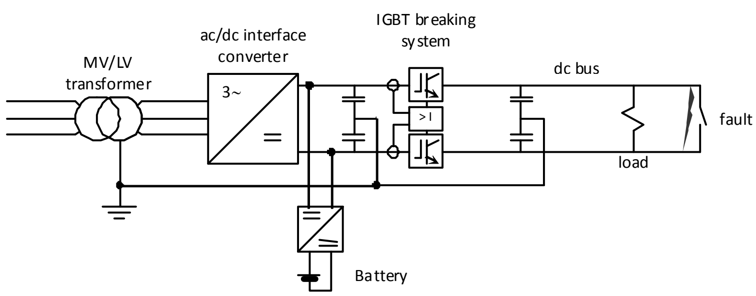

Fig. 5. Layout of the dc system protection investigation

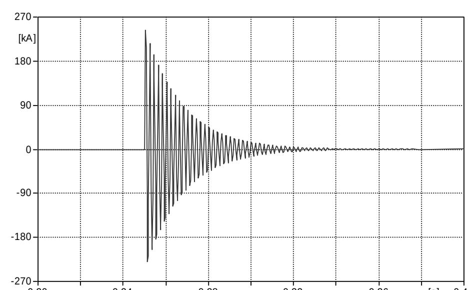

Fig. 6. DC fault current

Afterwards the breaking system intervention, the voltages grow as in the first instances after the fault occurrence, the converter control system maintains unchanged the power exchanged with the ac system which is entirely stored in the dc capacitors installed across the dc bus of the VSC. The current flowing through the IGBT breaking system is illustrated in Fig. 8. When the current the 2000 A threshold, the relay command the breaking system opening, within milliseconds. The IGBT breaking system has the advantage to immediately limit the current, which is very important for the VSCs, which are difficultly supporting current spikes even of short duration. Once the current is dropped to zero, due the limiting circuit of within the IGBT breaking system, the opening of the breaker is conducted without the occurrence of dangerous electrical arc. The ac phase voltages are illustrated in Fig. 9. The voltages are not highly influenced by the dc fault transients. A small increase of the ac voltage, due to the small voltage drop, is occurring.

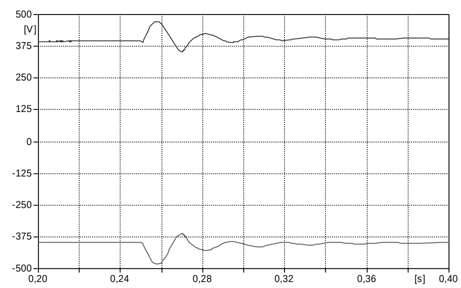

Fig. 7. DC voltages upstream the IGBT breaking systems

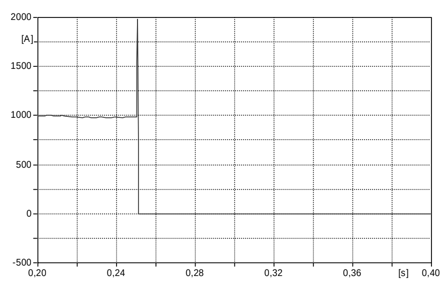

Fig. 8. Current flowing within the IGBT breaking system

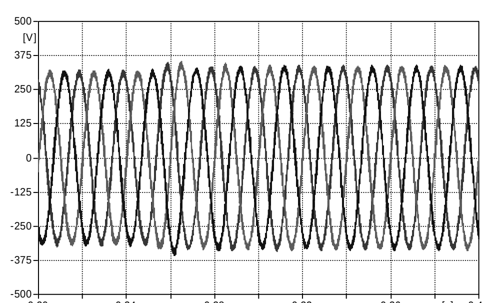

Fig. 9. AC system phase voltages.

6. Conclusions

The possible use of the dc distribution networks for residential loads has been analyzed, where the multiple positive aspects have been highlighted. The energy management of the proposed dc grid requires the choice of an optimal control strategy for obtaining the best performances of the system through: realization of a bidirectional flow ac-dc; insurance of a high degree of voltage quality and supply continuity; interconnection and efficient use of DG and storage systems. As the ac fault protection system does not represent such a difficult task, the dc circuit breaking has been covered. A protection strategy using an IGBT breaking system is used. The fast and safe isolation of the dc fault, such that the dc distribution system equipments are not damages, is the most challenging task. The simulations demonstrate the feasibility and correct operation of the system control logic and the dc protection strategy.

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