INTERNATIONAL RESEARCH JOURNAL IN ADVANCED ENGINEERING AND TECHNOLOGY (IRJAET) E - ISSN: 2454-4752 P - ISSN : 2454-4744
VOL 2 ISSUE 2 (2016) PAGES 734-738
RECEIVED : 22/03/2016. PUBLISHED : 29/03/2016

MODULAR MULTILEVEL CONVERTER BASED HVDC SYSTEM FOR GRID

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Abstract:

Large offshore wind farms will require an extensive sub-sea power network to provide internal interconnection. Present solutions are based around conventional medium-voltage AC architectures. This paper proposes an alternative DC collection network based around modular DC/DC converters with input-parallel-output-series (IPOS) connection. Small- signal analysis of the converter is presented, to assist in control scheme development for the converter input and output stages. A Lyapunov controller is embedded within the conventional output voltage sharing control loop. A master- slave control scheme is proposed to ensure power sharing under a range of operating conditions, and provides fault- tolerant operation since the status of 'master' can be reallocated in the event that the present 'master' module fails.

Keywords: DC/DC converter, IPOS connection, Power sharing, Lyapunov controller, n+1 redundancy.

1. INTRODUCTION

In comparison with an AC network, a DC collection grid offers a number of potential benefits. The use of DC can better utilise the cable voltage rating and eliminates the charging current associated with long AC cables. These issues may become of increasing importance as the capacity and area of offshore wind farms increase. A medium-voltage DC collection grid also has the potential to reduce losses through the use of medium-voltage converters and better optimisation of conversion stages [1]. Additionally, a DC collection grid may reduce the size and weight of the required plant and power units [1].

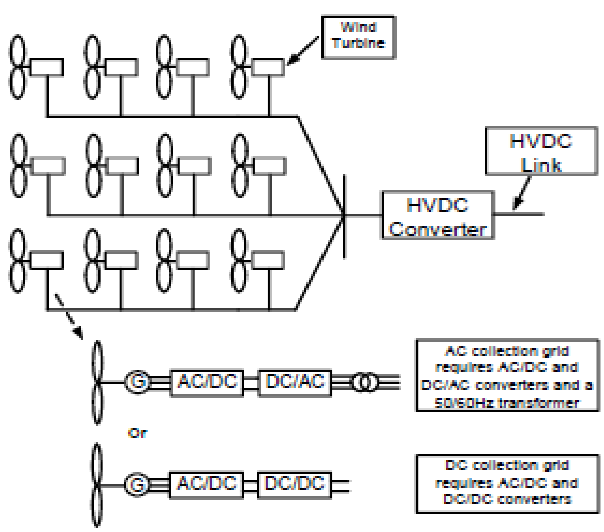

Fig.1. Offshore wind farm AC and DC collection grids

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Present offshore farms connect to conventional 50 or 60Hz AC systems by employing mains- frequency transformers to step up the generator output voltage to collection network voltage levels. Advances in DC/DC converters, particularly High-Frequency (HF) technologies [2, 3], allow the heavy line-frequency transformer in an AC grid to be replaced by a high- or medium-frequency transformer, leading to significant weight and size savings. Modular multilevel approaches to high-voltage conversion have achieved significant gains in HVDC applications. The effectiveness of such techniques is, however, limited in DC/DC applications [4, 5]. Instead, a more compact and lighter design that uses a few modules arranged in a parallel- series topology could provide a replacement for a conventional single converter that uses high-voltage valves comprising several series-connected switching devices to enable operation at medium-voltage.

2. CONTROL THEORY

The small-signal equivalent circuit of two IPOS connected PS-FB converters, shown in Fig.3, is given as an example, where k1 and k2 are the transformer turn ratios, Lr is the transformer leakage inductance, De is effective duty ratio per module [7], Lf1, Lf2, Cf1 and Cf2 are filter inductances and capacitances for modules 1 and 2 respectively, input voltage perturbation is represented by Δvin, input current perturbations for the two modules are Δiin1 and Δiin2 respectively, filter inductor current and capacitor voltage perturbations are represented by Δilf1, Δilf2, Δvo1, Δvo2 respectively, Δd1 and Δd2 are duty ratio perturbations, and Δdv1, Δdv2, Δdi1 and Δdi2 respectively represent duty ratio perturbations due to input voltage and output current,

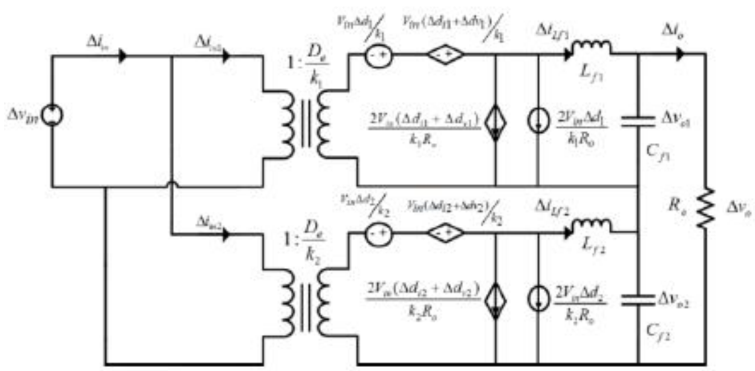


Fig.2. Small-signal equivalent circuit of the IPOS connected two-module system

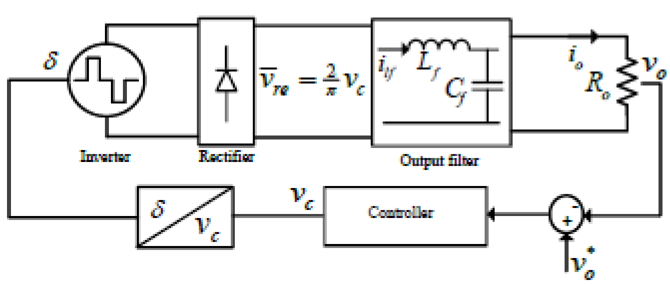
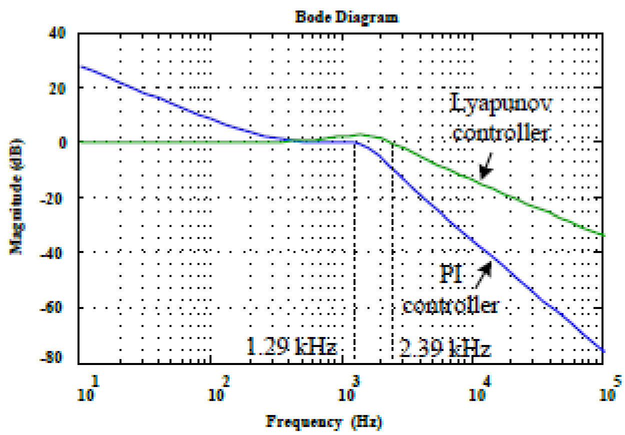


Fig.3. Closed-loop output voltage control

A linearised control scheme for a single DC/DC converter, and a novel reduced equivalent model of the IPOS DC/DC converter incorporating closed-loop output voltage A linearised control scheme for a single DC/DC converter, and a novel reduced equivalent model of the IPOS DC/DC converter incorporating closed-loop output voltage.



Fg.4. Closed loop band width

The multi-module DC/DC converter has internal fault management capability, in that faulty modules may be bypassed in order to allow continued system operation without any performance degradation. Such a feature is normally achievable by incorporating redundant modules to allow re-configuration of the power circuit and bypassing of the faulty modules. The modularity feature allows (n+k) redundancy, where n is the number of modules required to ensure that each module operates within its voltage rating, and k is the number of redundant modules that can be used to replace k faulty modules and maintain an uninterrupted operation. (n+1) redundancy is introduced in this circuit.

3. SIMULATION RESULTS

In order to evaluate the proposed control scheme for the IPOS DC/DC converter, a system consisting of a generator, a fully-rated uncontrolled rectifier and an IPOS DC/DC converter with rated output power

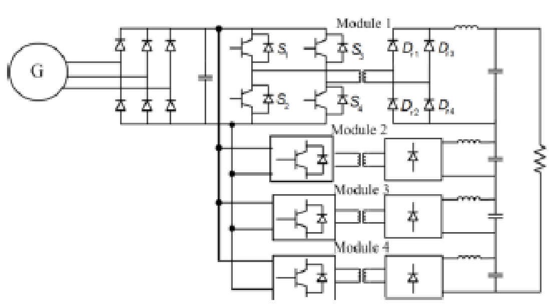


Fig.5. High-power system used in fault study

of 5MW, is simulated. Generator output voltage is 2500V at 50Hz, the high-frequency transformer operates at 5kHz and has a turns ratio of 2500:8250V, and the load voltage is maintained at 33kV. Module 1 is initially chosen as the master module. To test the effectiveness of the power balancing function, mismatches of +10% in transformer turns ratio of Module 1 and +10% in the output filter capacitor of Module 2 are introduced. Meanwhile, a permanent short-circuit fault is applied at the output terminals of Module 1 at t=50ms.It presents selected simulation results.

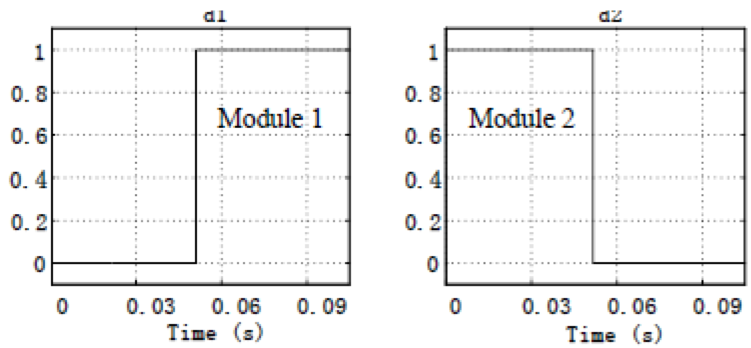


Fig.6. Output modulation

The results show that, before the fault, the proposed control scheme ensures output voltage balancing among the modules despite the mismatches in various module parameters. Following the fault at t=50ms, the faulty module is isolated and the output voltages of the remaining healthy modules are boosted to compensate the lost module. Output voltage vo is maintained at its pre-fault value and is shared equally between the healthy modules. The proposed control scheme manages failure of the master module, whilst ensuring continuous operation of and equal voltage sharing among the remaining healthy modules.

CONCLUSION

A ‘master-slave’ control strategy for DC/DC converters facilitates power sharing with mismatched components among the modules is proposed. The previous fixed ‘master- slave’ scheme can respond appropriately to slave module faults only, necessitating development of an enhanced controller based on the concept of the ‘non-dedicated master’ that permits arbitrary reallocation of the role of ‘master’ to another healthy module. The system has been verified through simulation of a fully-rated wind turbine module and the proposed control strategy can be extended to converters composed from any number of modules. The results show that the system exploits true (n+1) redundancy in the event that the master module is faulted.

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