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Grid Integration of a Dual Two-Level Voltage-Source Inverter considering Grid Impedance and Phase-Locked Loop

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***Abstract*—This paper proposes a dual two-level voltage-source inverter (DTL VSI) and its control to effectively integrate two dc sources into the multi-infeed ac/dc (MIACDC) power architecture of fully integrated power and energy systems (FIPESs). The current-controlled method is also synthesized and proposed to control the grid-connected DTL VSI. To this end, this article provides mathematical analyses comparing the DTL VSI with the conventional current-controlled grid-connected two-level VSIs (TL VSIs). The linearized state-space models of both systems are mathematically derived for analyzing the dynamics of both structures. These models reveal the salient feature of the proposed DTL VSIs used in grid integration. To this end, space-phasor analysis is employed, and the dynamics of the phase-locked loop (PLL) and the grid impedance are also considered. The proposed grid-connected DTL VSI (with the current-controlled algorithm) not only in weak grids (for normal grid conditions) but even after fault removal (for faulty grid conditions) stabilizes the active and reactive power dynamics with improved transient performance compared to that of its conventional counterpart. Therefore, it enhances the operation range of the VSIs integrating various entities in FIPES' MIACDC power architecture. This paper provides supportive simulation results and experiments generated by MATLAB and a scaled-down test rig, respectively.**

***Index Terms*—Dual two-level voltage-source inverter (DTL VSI), phase-locked loop (PLL) dynamics, space-phasor vector control, two-level voltage-source inverter (TL VSI), voltage-source inverter (VSI), weak grids.**

I. Introduction

Due to the significant amount of green gas emitted by human beings, and by considering its irrecoverable effects on the environment, many countries adopt renewables as an alternative to fossil fuels. Therefore, the energy sector has been significantly progressing and moving toward integrating power networks and energy storage systems, which forms the fully integrated power and energy systems (FIPESs). Energy storage systems will be mostly in the form of battery systems embedded in ac/dc grids. FIPESs use multi-infeed ac/dc (MIACDC) power systems. MIACDC simpler versions are found in super grids and meshed high-voltage direct current grids—in transmission systems—and hybrid multi-terminal ac/dc grids—in both distribution systems and modernized microgrids (MMGs) [1]. They have been employed in smart grids nowadays. In smart grids, the upgraded MIACDC concept brings many benefits to the operation, control, and demand supply within commercial power systems.

Thanks to the essential advances brought to the field of power electronics and semiconductor devices, different types of inverters are employed to connect renewables and sources to MIACDC power architecture of FIPESs [2]–[8]. Among different structures of voltage-source inverters (VSIs), dual two-level VSIs (DTL VSIs) are well-known due to its significant advantages brought in motor and drive controls (e.g., voltage THD, voltage weighted THD and switching losses, etc.) [9], [10].

The DTL VSI can be one of the up-and-coming power electronic topologies—which is employed in the FIPESs of MMGs. DTL VSIs empower an FIPES to be able to benefit from the MIACDC power systems' architecture. DTL VSI can be implemented by either a single dc source or two separate dc sources. Nonetheless, DTL VSI with two dc sources benefits from lower voltage and current THD, lack of circulating currents, and two isolated paths for transferring power to the power grid [9], [10]. The lower voltage and current THDs lead to a decrease in the cost of installation and maintenance decreases. Additionally, by utilizing two separate paths, the reliability of the system is augmented since, in case of missing one of the paths, another path is still able to transfer a portion of power. In comparison with systems containing single VSIs, DTL VSI provides some substantial benefits. For instance, with the given nominal power, this structure reduces the total manufacturing and installation cost [11]. Furthermore, DTL VSIs benefit from a higher magnitude of the output voltage with the same amount of dc-link voltage compared to VSI. This advantage reduces the turn ratio and output impedance of the transformer needed to step up the output voltage of the DTL VSI. Besides, the reliability of the system employing DTL VSI is improved because of using two paths of power supply. Therefore, inverters based on dual configurations attract more attention, and they are commonly utilized in grid-connected photovoltaic systems [11]–[14].

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