The Dynamic Simulation of Offshore Wind Power System using High Voltage Direct Current

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I. Preface

In response to the policy goal of achieving net-zero carbon emissions by 2050, countries worldwide strive to increase the penetration of renewable energy to reduce their reliance on fossil fuels. Therefore, our country is actively developing renewable energy, among which offshore wind power is one of the major technologies. Taiwan's primary electricity demand center is located in the northern region. However, with the decommissioning of many northern power plants, there is expected to be a tightening of power supply. Therefore, this study explores the use of high-voltage direct current (HVDC) transmission to supply offshore wind power from the central offshore area to the northern electricity consumption region. The location of the wind farm and connected point are shown in Fig. 1. The evaluation content includes two methods, which are fault analysis and impedance scan. Fault analysis can determine the system's status after fault, and an impedance scan can understand the system's stability after connecting the HVDC line.

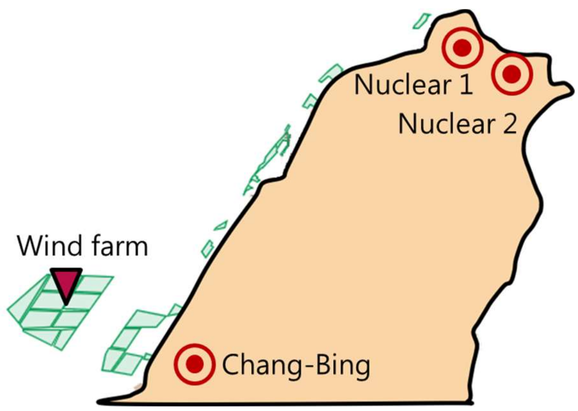

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Fig. 1 The location of the wind farm and connected point in north Taiwan

II. Research methodology

Generally, wind farms are often arranged in parallel to capture wind power effectively, consisting of several to hundreds of wind power turbines in a single farm. In terms of simulation, the presence of numerous wind turbines can significantly delay simulation efficacy, posing a challenge to our equipment's capability to handle the simulation. Therefore, it becomes necessary to equivalize the wind power plant to ensure a smooth simulation process. The simplified equivalent type is illustrated in Fig. 2. Three cases are considered to assess the feasibility of the equivalent method: 1. Five origin plants 2. Single plant, five times capacity and origin impedance 3. Single plant, five times capacity and equivalent impedance. The result indicates that, after a three-phase ground fault, case 3 is similar to case 1 shown in Fig. 3. Based on these findings, the validity of the equivalent method is confirmed.

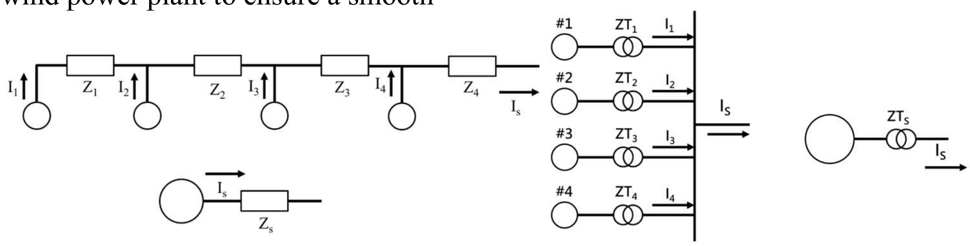

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Fig. 2 The equivalence method of large number wind power machine (L) series (R) parallel

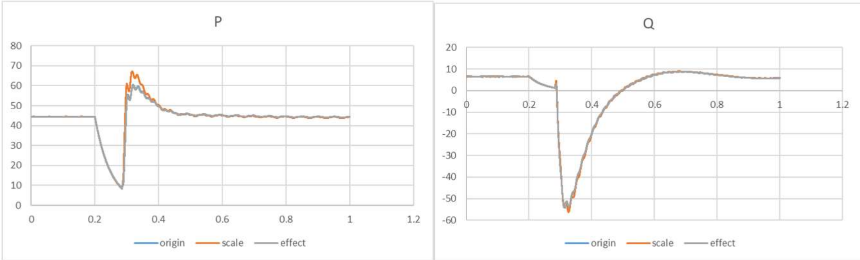

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Fig. 3 (L)Real power (R)Reactive power for different equivalent methods

The following analysis is based on the equivalent method. First, the line structure for fault analysis is shown in Fig. 4, where the fault is located on the AC side near the wind farm and on the DC side in the HVDC transmission line.

Before the fault, it was confirmed that the bus voltage in the northern Taiwan region during peak/off-peak load with full/empty wind power supply was not over 1.05 pu, which follows the operator's requirement for system stability.

Fig. 5 and Fig. 6 show the power flow and voltage on the AC/DC side after the fault, respectively. In the case of an AC fault, there is a deviation from the normal conditions as the power flow reverses during the fault time, which doesn't occur in a DC fault. On the other hand, the voltage exhibits smoother behavior in AC faults based on separation by HVDC lines compared with DC faults.

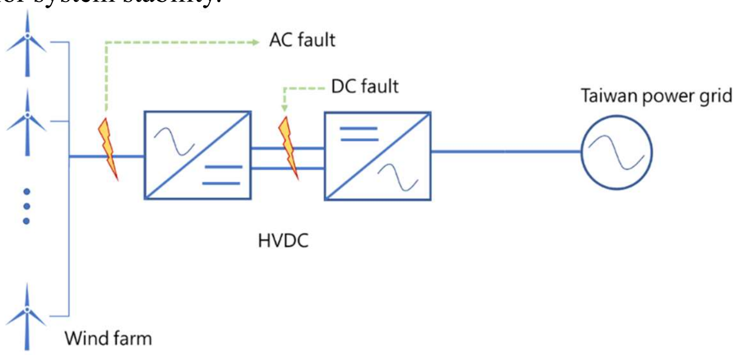

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Fig. 4 The location of the fault

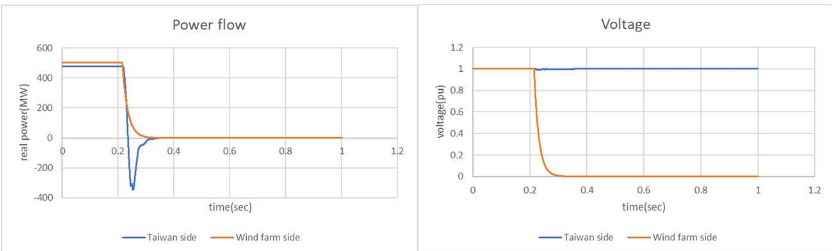

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Fig. 5 The (L)power flow (R)voltage result after the AC fault

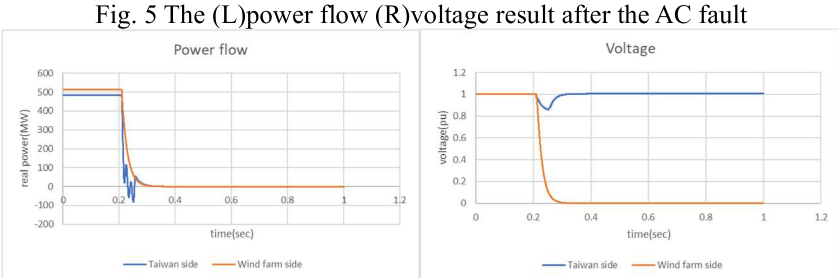

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Fig. 6 The (L)power flow (R)voltage result after DC fault

Unlike synchronous machines, HVDC and wind power plants are inverter-based resource(IBR) equipment comprised of power electronic devices. These devices produce a high-order harmonic that may impact grid stability. Therefore, understanding the impact of connecting new equipment involves conducting a frequency impedance scan. The scan structure is shown in Fig. 7, where a testing signal in the frequency range of 1~1k Hz is sent to the grid and test equipment at the Point of Interaction(POI). The output current is measured, and the impedance is calculated per Hz. The impedance results obtained through this method are shown in Fig. 8. According to the Phase Margin theory, the interaction of magnitude at the grid and HVDC (as Fig. 8(L) located on 108-110Hz) can be considered stable when the angle is smaller than 180° (as Fig. 8(R) about 76-78°).

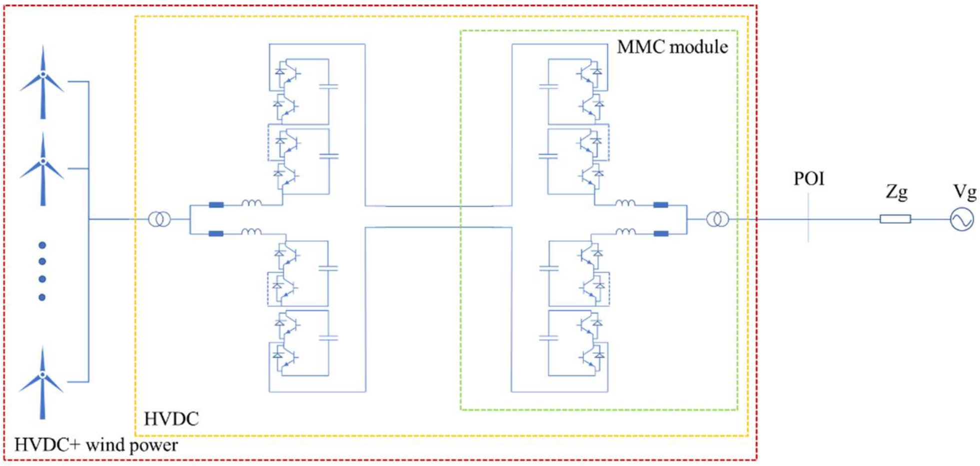

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Fig. 7 The structure of HVDC and different scan area

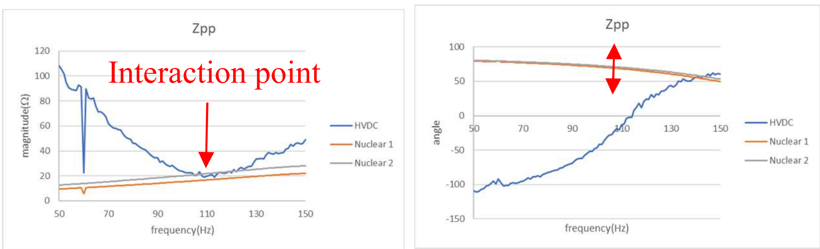

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Fig. 8 Analysis of impedance scan on power grid and HVDC (L) magnitude (R) angle

III. Conclusion

The study focuses on technical simulation evaluation of transmitting offshore wind power to the northern load center using HVDC. The test methods are fault analysis and impedance scan. The fault analysis observed that the stable bus voltage didn’t exceed the operator’s requirement. On the other hand, in the case of an AC fault, the voltage exhibited smoother behavior compared to a DC fault. The impedance scan results indicated that the angle was consistently smaller than 180°, suggesting that the system doesn’t transition into a positive feedback system. Consequently, it can be concluded that the Taiwan grid connected with HVDC is stable. Based on the simulation, the transmission of offshore wind power to the northern load center using HVDC is deemed feasible. However, it’s important to note that this study employed a general model for simulation analysis. In the event of future construction plans, a more detailed analysis using Site-Specific models provided by equipment manufacturers should be conducted to ensure the safe operation of the system.