Inverter-Based Renewable Energy Systems: Addressing Integration Challenges through Innovative Control Strategies

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Abstract: **The increasing penetration of inverter-based renewable energy sources (IBRES) in the grid poses significant integration challenges. This paper reviews the control strategies and power quality issues associated with IBRES and discusses potential solutions to address this challenge. The IBRs in the plant use a voltage source inverter topology combined with a grid-connected filter. The control structure of the IBR includes a cascaded loop control where an inner current control and outer power control are designed in the dq-reference frame, and a closed-loop phase-locked loop is used for the grid synchronization. The mathematical study is conducted first to develop aggregated plant models considering different operating scenarios of active IBRs in an IBR plant. Then, an electromagnetic transient simulation (EMT) model of the plant is developed to investigate the plant's dynamic performance under different operating scenarios. This paper proposes a novel approach to model an IBR plant, which can capture the transient nature at the plant level, detailed IBR control at the inverter level, interactions of multiple IBR groups in a plant structure, and a collector system connecting the IBRs to the grid.**

Keywords: inverter-based resources plant; aggregated plant model; electromagnetic transient simulation; vector control; grid-connected filters. We also discuss the importance of grid code compliance and the need for standardized communication protocols.

I.INTRODUCTION

Renewable energy resources (RESs), such as wind turbines and solar photovoltaic (PV) modules, are typically connected to the grid using inverters, and are therefore named inverter-based resources (IBRs) [1]. With the fast growth of renewable energy, solar and wind in plant structures are emerging rapidly worldwide. An IBR plant consists of a huge number of IBR units connected together via a collector system at a single location [3], and, after that, the aggregated power is transported through a transmission line and sent to the grid. An IBR operation is different and complicated compared to that of a synchronous generator as it has more complicated dynamics. When hundreds of IBRs are tied together and operate as a plant, the transient complexity increases enormously, and its impact on the grid can vary based on different IBR configurations in the plant [4].

In order to analyze the impact of an IBR plant on the bulk power system (BPS), it is important to develop a transient simulation model that is computationally affordable and can accurately portray the control of the IBRs at the inverter level, as well as the interconnection dynamics of the plant with the grid. Most developments of the IBR plant model available in the literature are related to wind power plants (WPP) [5,6,7]. In [8], an equivalent impedance model of a WPP collector system is proposed for power system planning studies, where the wind turbines are set up in series and parallel arrangements. However, detailed transient modeling of IBRs within the plant is absent in [8], and no EMT simulation is performed. Another WPP equivalent model is proposed in [9], which reduces the plant model containing a fixed number of 168 wind turbines into an equivalent model with one or two machines connected to the grid via one or two lines representing the equivalent collector system.

"Inverter-Based Renewable Energy Systems: Addressing Integration Challenges through Innovative Control Strategies" is a crucial and rapidly evolving area of research and development within the power systems domain. It focuses on the effective and reliable integration of renewable energy sources (RES) like solar photovoltaic (PV) and wind power into the electrical grid using power electronic inverters.

The growing demand for renewable energy sources has led to an increase in the penetration of inverter-based renewable energy sources (IBRES) in the grid. However, the integration of IBRES poses significant

challenges, including power quality issues, grid stability concerns, and reliability problems. This paper reviews the control strategies and power quality issues associated with IBRES and discusses potential solutions to address these challenges.

II SYSTEM MODELLING

Modeling an inverter-based renewable energy system involves creating mathematical representations and simulations to understand its behavior and interaction with the power grid or local loads.

The IBR family typically includes solar PV generators, wind turbine (WT) generators such as doubly fed induction generators (Type-3), permanent magnet synchronous generators (Type-4), and energy storage systems [26]. Except for the Type-3 WT (not the focus of this paper), IBRs are connected to the BPS through a full-size dc/ac converter system (Figure 1a), which includes four main components: (i) a converter at the source-side, (ii) a capacitor at the dc-link, (iii) a converter at the grid-side, and (iv) a grid connected filter [27,28,29]. The converter at the source-side controls the energy supply of solar or wind, or performs energy management of the energy storage system, and is an ac/dc type for a Type-4 WT and a dc/dc type for a solar PV and energy storage system. The grid-side converter regulates reactive power flow at the point of common coupling (PCC) and maintains a fixed dc-link voltage and is always a dc/ac type.
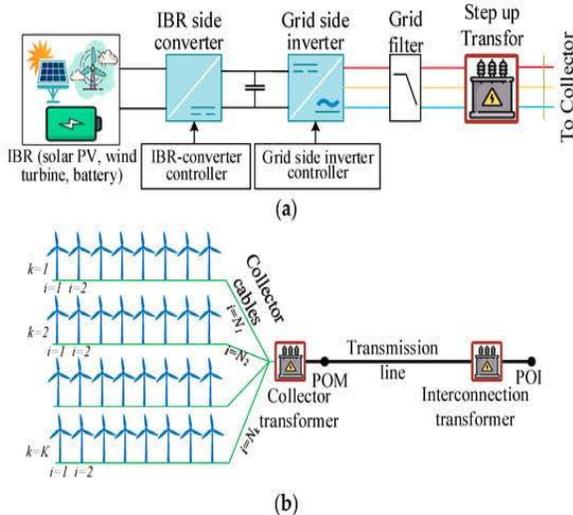

Figure 1: A generalized diagram of (a) a full-scale IBR system and (b) a grid connected WPP

An IBR operating in an IBR plant can be assumed to have a constant dc-link voltage with a controller for the grid-side inverter, which consists of a back-to-back inner current control loop and an outer power (active/reactive) or bus voltage control loop
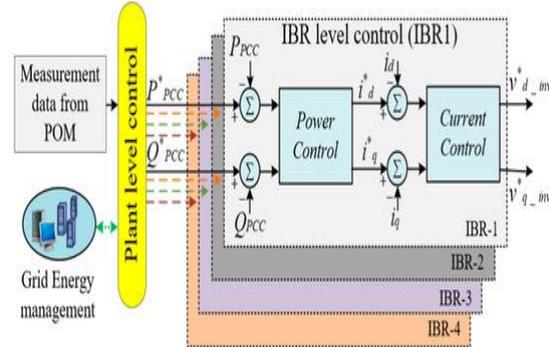

Figure 2: Plant level and IBR level controller structure of an inverter interfaced IBR plant.

An IBR is usually interfaced to the collector system through a passive filter. The filter could be L, LC, or LCL type. Figure 3 shows the circuit diagram of an IBR connected to the grid via an LCL-filter. In the figure, RfI and LfI represent the inverter-side filter resistance and inductance, RfG and LfG denote the grid-side filter resistance and inductance, C stands for the filter capacitance, and Rg and Lg represent the equivalent grid resistance and inductance from the PCC.
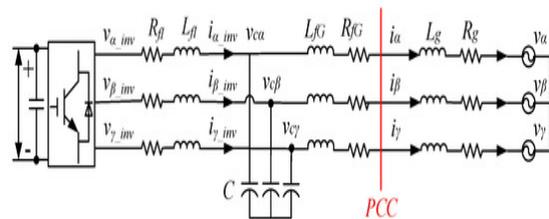

Figure 3: Schematic diagram of an LCL-filter interfaced IBR unit.

III SYSTEM ANALYSIS

For Case 1, the impedance of the collector system is not considered and the parameters for all the IBRs in the plant are the same. The total number of IBRs is 600. Regarding the LCL filter parameters of an IBR, the capacitance is 25 µF while the inductance is 0.2 mH, and the resistance of the filter inductor is 0.0015 Ω for both the inverter- and grid-side inductors
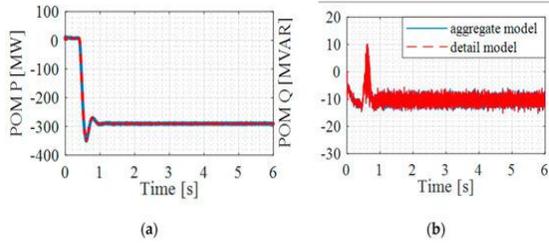
Figure 4: Active and reactive power at the POM for Case 1 using aggregated and detailed models: (a) Active power, (b) Reactive Power.

For Case 2, All IBRs within the IBR plant have the same LCL filter parameters in this case, but they are not synchronized and deliver different output voltages. Hence, the power reference of each IBR is different in the detailed model. The power reference of the average IBR in the aggregated model is the average of the power references of all the IBRs, according to (32). Figure 12 shows the active and reactive power at the POM of the IBR plant.
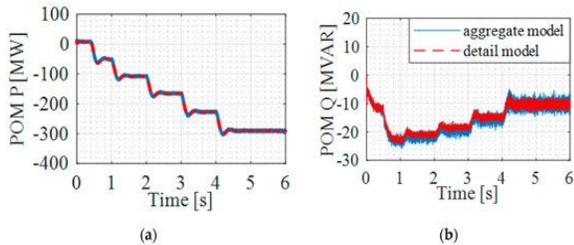

Figure 5: Active and reactive power at the POM for Case 2 using aggregated and detailed models: (a) Active power, (b) Reactive Power.

For Case 3, all the IBRs within the IBR plant have different LCL filter parameters, deliver different IBR output voltages, and are connected in parallel with different collector impedances to the POM. For the detail model, a perturbation of 20% on filter inductance and resistance is applied to obtain a random value of the filter parameters.
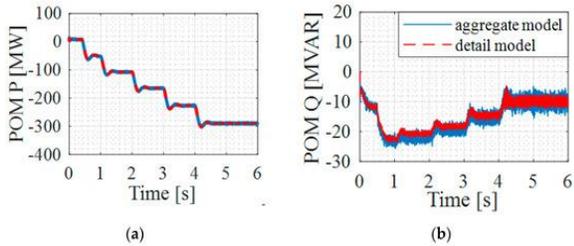

Figure 6: Active and reactive power at the POM for Case 3 using aggregated and detailed models: (a) Active power, (b) Reactive Power.

IV. RESULT AND DISCUSSION

For analysis, the performance of the proposed IBR plant during a fault event in the grid is analyzed. A real world event reported by Electric Reliability Council of Texas (ERCOT) in is taken into account, where a type-4 WPP is connected to the grid, and a three phase to ground fault occurs, resulting abnormal operation in the WPP. To perform the analysis, the most comprehensive model, with the IBRs arranged in series and parallel combinations is considered.

V. CONCLUSION

The integration of IBRES poses significant challenges, including power quality issues and grid stability concerns. Advanced control techniques, such as MPC and reinforcement learning, can help address these challenges and improve the integration of IBRES. The aggregated model has incorporated different aspects of an IBR plant, as well as IBR configurations within the plant, such as collector system impacts, grid-connected filters of the IBR inverter, detailed control configurations at the inverter level, series/parallel orientation of IBRs within the plant, etc. Standardized communication protocols and grid code compliance are also essential for ensuring the reliable operation of IBRES. The study and evaluation results show that the proposed IBR plant model is effective and accurate in investigating the interconnection of an IBR plant, with the grid as well as IBR controllers, at the inverter level in a plant configuration scenario.

REFERENCE

[1] Lu, B.; Li, S.; Gao, Y.; Das, H.S. P-Q Capability Analysis of Inverter Based Resources with Typical Grid Connected Filters. In Proceedings of the 2020 IEEE Power & Energy Society General Meeting

[2] IEEE 2800-2022; IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems. IEEE: Manhattan, NY, USA, 22 April 2022.

[3] Xie, X.; Zhang, X.; Liu, H.; Liu, H.; Li, Y.; Zhang, C. Characteristic Analysis of Subsynchronous Resonance in Practical Wind Farms Connected to

Series-Compensated Transmissions. IEEE Trans. Energy Convers.

[4] Alenius, H.; De Jong, E.; Burstein, A.; Fabian, A. Identification of Three-Phase Grid Impedance in the Presence of Parallel Converters. Energies 2019, 12, 2674.

[5] Gul, M.U.; Ahmed, A.; Warraich, A. A practical method for equivalencing of a large wind farm with multiple turbine representation. In Proceedings of the 2018 IEEE 7th International Conference on Power and Energy (PECon),

[6] Kim, D.-E.; El-Sharkawi, M.A. Dynamic Equivalent Model of Wind Power Plant Using Parameter Identification. IEEE Trans. Energy Convers. 2015, 31, 37–45. [Google Scholar] [CrossRef]

[7] Kim, D.-E.; El-Sharkawi, M.A. Dynamic Equivalent Model of Wind Power Plant Using an Aggregation Technique. IEEE Trans. Energy Convers. 2015, 30, 1639–1649. [Google Scholar] [CrossRef]

[8] Muljadi, E.; Pasupulati, S.; Ellis, A.; Kosterov, D. Method of equivalencing for a large wind power plant with multiple turbine representation. In Proceedings of the 2008 IEEE.