Enhancement of a Grid-Following Inverter with Grid-Forming Support under Weak Grid Conditions

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***Abstract*— The increasing penetration of renewable energy-based inverter-interfaced resources has made modern power systems more sensitive to weak-grid conditions. In particular, Grid-Following (GFL) inverters rely on phase-locked loop (PLL)-based synchronization, which may lead to stability challenges under weak-grid operation. This study investigates the potential of Grid-Forming (GFM) support to enhance the stability of GFL inverters in weak-grid environments. The operating characteristics of GFL and GFM control strategies are reviewed, and a simplified dynamic simulation model is developed to evaluate their transient performance under various disturbance scenarios. Voltage sag, load step change, and grid-strength variation (SCR variation) conditions are analyzed and compared in terms of frequency response, voltage regulation, and synchronization performance. The results indicate that the incorporation of GFM support reduces oscillations, improves voltage and frequency stability, and enhances dynamic system response under weak-grid conditions. Therefore, GFM-assisted architecture represents a promising solution for improving the stability and reliability of inverter-dominated power systems with low inertia and weak-grid characteristics.**

Keywords*— *grid-following inverter, grid-forming inverter, weak grid operation, PLL synchronization, dynamic stability.

I. INTRODUCTION

The increasing integration of renewable energy sources and inverter-based resources (IBRs) has significantly transformed modern power systems [1], [9]. As the penetration of power-electronics-interfaced generation increases, system inertia and short-circuit capacity decrease, leading to a growing prevalence of weak-grid conditions [3]. Previous studies have shown that grid-following (GFL) inverters may experience stability challenges under weak-grid conditions due to their reliance on phase-locked loop (PLL)-based synchronization [2], [5]. High grid impedance and low short-circuit ratio (SCR) can increase inverter-grid interactions, resulting in voltage fluctuations, frequency oscillations, and synchronization instability [2], [4], [5]. To address these issues, grid-forming (GFM) inverters have been proposed as an effective solution for improving weak-grid stability [6], [7]. Unlike conventional GFL inverters, GFM inverters can independently establish voltage and frequency references, providing voltage support, frequency regulation, and synthetic inertia [3], [6]. Recent studies have demonstrated that GFM control strategies can enhance transient performance and system stability under low-inertia operating conditions [6], [8].

Therefore, this study investigates the stability of a grid-following inverter operating under weak-grid conditions and evaluates the effectiveness of grid-forming support in improving system dynamic performance. To achieve this objective, a comparative simulation-based dynamic response analysis is conducted using a hybrid GFL–GFM model developed in MATLAB/Simulink. The system performance is evaluated under voltage sag, load step change, and grid-strength variation scenarios.

II. SYSTEM ARCHITECTURE AND CONTROL STRATEGY

A. Weak Grid System Model

Weak grids are characterized by a low short-circuit ratio, high grid impedance, and reduced system inertia [3], [5]. Under such conditions, power systems become more sensitive to voltage and frequency variations, making them more vulnerable to dynamic instability during disturbances. As the penetration of inverter-based renewable energy sources continues to increase, the contribution of conventional synchronous generators decreases, resulting in a growing prevalence of weak-grid conditions in modern power systems. GFL inverters rely on PLL-based synchronization to track the grid voltage and frequency. Consequently, their performance becomes highly sensitive to grid impedance under weak-grid conditions. This may lead to increased inverter-grid interactions, resulting in voltage fluctuations, frequency oscillations, and synchronization instability. In particular, a reduction in short-circuit capacity can degrade PLL dynamic performance and prolong system recovery following transient disturbances.

To represent weak-grid conditions, a simplified power system model with high grid impedance and a low SCR was developed. The study system consists of a grid-following inverter, grid-forming support, and a load component. The voltage response, frequency response, and synchronization performance of the system under disturbance conditions were analyzed and compared using MATLAB/Simulink simulations.

B. Grid-Following Inverter Control

A Grid-Following (GFL) inverter is a current-controlled converter that operates by using the grid voltage and