UNIVERSITAS
GADJAH MADA
Dynamic Modeling of Photovoltaic Systems With Grid-Connected Inverters: Stability Analysis of Grid Strength And Control Parameter Variations
Farel Sijabat, Husni Rois Ali, S.T., M.Eng., Ph.D., DIC., SMIEEE. ; Ir. Lesnanto Multa Putranto, S.T., M.Eng., Ph.D., I
Universitas Gadjah Mada, 2026 | Diunduh dari http://etd.repository.ugm.ac.id/

ABSTRACT

The global transition toward renewable energy has driven the massive integration of solar photovoltaics (PV), which are interfaced to the grid entirely through Inverter-Based Resources (IBRs). While Grid-Following (GFL) control remains the industry standard for commercial PV plants, the gradual retirement of synchronous generators results in weakened grids with declining Short Circuit Ratios (SCR), severely threatening Phase-Locked Loop (PLL) synchronization. Because commercial black-box software obscures internal mathematical states, diagnosing the root causes of these emerging instabilities is highly restrictive. To address this gap, this study formulates a fully transparent, modular Differential-Algebraic Equation (DAE) framework of a grid-tied GFL PV system to rigorously evaluate its large-signal behavior and small-signal stability landscape. The developed model is subjected to time-domain transient simulations—benchmarked against EN 50530 and IEC 62109 standards, as well as symmetrical grid faults—and comprehensive small-signal eigenvalue sweeps varying physical grid strength, DC-link capacitance, and controller gains. Time-domain results validate the framework's accuracy in replicating commercial PV array datasheets and robust fault recovery. Small-signal analysis confirms that physical grid weakening and DC-link capacitor degradation significantly compress system stability margins, driving dominant modes closer to the right-half plane. Crucially, participation factor analysis reveals a complex interactions in weak grids: while aggressive PLL tuning exacerbates synchronization instability, optimal tuning reverses this trajectory, fundamentally shifting the primary system vulnerability onto the DC-link and inner inverter control states. These findings provide critical diagnostic insights into the internal operational boundaries of GFL inverters under degrading grid conditions.

Keywords: Solar Photovoltaics, Grid-Following Inverter, Differential-Algebraic Equations, Small-Signal Stability, Short Circuit Ratio, Phase-Locked Loop.