

# ANN-Based Power and Current Limiting Strategy for Grid-Connected Distributed Generation Systems: A Review

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**Abstract** This review paper comprehensively surveys the state-of-the-art in power and current limiting strategies for Grid-Connected Droop-Controlled Distributed Generators (GCDCDGs). The paper traces the evolution from conventional Proportional-Integral (PI) controllers through Artificial Neural Network (ANN) based controllers to Model Predictive Controllers (MPC), examining their relative merits and limitations in managing abnormal upstream grid conditions. Key issues addressed include current limitation under upstream grid (UG) frequency and voltage magnitude drops, balanced and unbalanced load injection scenarios, and Total Harmonic Distortion (THD) performance. Simulation results from MATLAB/Simulink studies demonstrate that ANN-based controllers achieve approximately 50% reduction in THD compared to PI controllers, while MPC achieves the lowest THD at less than 1%. The paper concludes that ANN-based controllers represent an optimal trade-off between performance and computational complexity, making them suitable for practical deployment. Future research directions including MPC-supervised ANN controllers are identified.

**Keywords:** Droop control, Distributed generation, ANN, MPC, PI controller, Current limiting, THD, Grid-connected inverter, Voltage source converter

## I. INTRODUCTION

Grid-connected distributed generation (DG) systems have become increasingly prevalent as the global energy landscape transitions toward renewable and decentralized power production. These small-scale power plants, typically interfaced with the utility grid through power electronic inverters, play a pivotal role in meeting modern energy demands. However, their widespread integration has introduced new challenges related to power system stability, power quality, and protection.

Central to the reliable operation of DG systems is the droop control mechanism, which enables inverter-interfaced DGs to contribute to frequency and voltage regulation without requiring communication links between individual units. Droop control has been extensively studied and is widely deployed in both islanded and grid-connected microgrids. Despite its proven effectiveness, conventional droop control faces critical limitations when the upstream grid (UG) experiences large frequency or voltage magnitude drops — scenarios that can cause inverter output currents and powers to exceed safe operating limits.

The current limiting challenge in GCDCDGs has two primary aspects: steady-state limiting during sustained abnormal grid

conditions, and transient limiting during dynamic disturbances such as load switching events. External current limiters and saturation units, while commonly employed, often introduce oscillations and instability into the control loop. This has motivated research into integrated, limitless current control strategies that can maintain system stability across all operating conditions.

Simultaneously, the control technology landscape for voltage source converters (VSCs) has been undergoing rapid evolution. The Proportional-Integral (PI) controller, long the workhorse of power electronics control, faces inherent limitations in bandwidth, nonlinearity handling, and disturbance rejection. Model Predictive Controllers offer superior dynamic performance but carry prohibitive computational costs for small-scale applications. Artificial Neural Networks have emerged as a promising middle ground, capable of replicating advanced controller performance with significantly reduced online computational burden.

This review paper systematically examines the progression from PI-based to ANN-based and MPC-based internal control strategies for GCDCDGs, with a particular focus on their interactions with droop-control-based current limiting strategies. The paper synthesizes findings from simulation studies and the broader literature to provide a comprehensive picture of the current state of the art and to identify promising avenues for future research.

## II LITERATURE REVIEW

Inverter-based distributed generators (DGs) are commonly equipped with droop control mechanisms to help maintain power system stability. This allows them to contribute to the overall power supply of the grid. Droop control is particularly beneficial in situations where communication between different inverter units is limited or unavailable [1]-[4]. A current-limiting droop controller should have the capability to be operated in the set mode to accurately send the desired power to the grid or in the droop mode to take part in the grid regulation, while maintaining the inverter current below a given value at all times [5].

Two main considerations arise concerning grid-connected distributed generators (GCDCDGs). The first involves the stability of droop control strategies, a topic that has been extensively researched [6]-[8]. The second pertains to ensuring that current levels remain below a specified maximum threshold [9]-[14]. Current-limiting controllers can effectively restrict current levels by activating specifically

designed protection circuits[16] or employing various Low-Voltage Ride Through (LVRT) structures [17],[18]. However, these methods pose challenges in proving their stability. External limiters and saturation units are frequently incorporated into current or voltage control loops to constrain output current. However, these additions can sometimes introduce unwanted oscillations and instability [9].

### III. METHODOLOGY

#### A. Conventional Droop Control Principles

Droop control establishes a proportional relationship between a DG's output power and its operating frequency (for active power) and terminal voltage (for reactive power). The reference DG frequency is governed by the well-known P-omega relationship, where the DG frequency decreases proportionally as active power output increases beyond the rated value. Similarly, the reference voltage magnitude decreases as reactive power output increases.

Under normal grid conditions, these droop characteristics allow the DG to track the upstream grid and supply rated power without requiring inter-unit communication. However, under abnormal conditions such as UG frequency drops caused by sudden load increases or generation deficits at the upstream level, the GCDG responds by increasing its active power injection. For large frequency drops, this response can drive the output current well beyond safe limits.

#### 3.2 Current Limiting in Conventional Droop Control

Traditional approaches to current limiting include external current limiters applied to the dq-frame current references and Low-Voltage Ride Through (LVRT) structures. While effective at constraining currents in steady state, these external limiters suffer from a fundamental conflict with the P-omega droop characteristic: when the active current component is saturated by a limiter, the DG frequency loses its ability to track the UG frequency, resulting in power oscillations and potential system instability.

Increasing the active power droop coefficient to limit power output is also constrained by stability boundaries. These limitations have driven the development of integrated droop-based current limiting strategies that avoid external limiters entirely.

#### 3.3 The Proposed Unified Droop-Based Current Limiting Strategy

The proposed strategy overcomes conventional limitations by introducing supplementary control signals that shift the droop characteristic curves when power limits are approached. The key innovation is the computation of offset terms that adjust the power references dynamically, ensuring that both steady-state power and transient instantaneous currents remain within prescribed boundaries.

Two PI-based supplementary controllers minimize the difference between filtered (steady-state) and instantaneous values of the dq-frame PCC currents,  $I_{od}$  and  $I_{oq}$ . These filtered signals are saturated at their maximum permissible values. Since steady-state power control is governed by the droop mechanism, current saturation does not interfere with system stability — a critical advantage over external limiter

approaches. This strategy has been validated under six distinct case scenarios covering frequency drops, voltage drops, balanced load injection, and induction motor load switching.

#### B. Internal Controller Strategies

##### PI-Based Internal Controller

The PI controller remains the most widely adopted control structure for VSC-based DG systems. Its dual-loop architecture — an outer voltage control loop generating dq-frame current references, and an inner current control loop generating PWM modulation signals — provides a well-understood and easily tunable framework. PI controllers offer elimination of steady-state error, fast dynamic response through the proportional term, and relative robustness to parameter variations.

However, PI controllers exhibit several well-documented limitations in the context of inverter-based DG control. These include limited control bandwidth that restricts dynamic performance during fast transients, difficulty in gain tuning for systems with multiple interacting operating points, sensitivity to varying grid impedance conditions, poor rejection of nonlinear disturbances, and reliance on accurate system parameter information. As renewable energy penetration increases and grid conditions become more dynamic and uncertain, these limitations become progressively more constraining.

##### ANN-Based Internal Controller

Artificial Neural Networks offer a fundamentally different approach to control: rather than relying on an explicit mathematical model of the system, ANNs learn input-output mappings from data. In the context of GCDG control, the ANN controller replaces the PI controllers in the outer voltage control loop, while retaining the inner current PI loop for robustness. The ANN inputs are the voltage error signals  $e_d$  and  $e_q$  in the dq frame, and the outputs are the compensating signals  $u_d$  and  $u_q$ .

The training data is generated by operating the GCDG system under the supervisory PI controller across four comprehensive test scenarios, capturing 400,000 data samples at a timestep of  $1e-5$  seconds. The Levenberg-Marquardt Backpropagation (LMBP) algorithm, one of the fastest convergence algorithms for neural network training, is employed. Data is partitioned as 70% training, 15% validation, and 15% testing to ensure generalization.

Critically, the training scenarios are carefully chosen to span the operating space of the DG system, including grid frequency change, grid voltage magnitude change, combined frequency and voltage change with balanced load injection, and combined disturbances with unbalanced motor load injection. This comprehensive training coverage ensures that the ANN generalizes effectively to the full range of abnormal grid conditions encountered in practice.

The ANN controller demonstrates significant performance improvements over the PI baseline: THD reductions of approximately 50% across all test cases, faster rise times and fall times for dq-frame currents, and markedly reduced noise content in output power and current waveforms. These improvements are achieved with comparable steady-state accuracy and current limiting effectiveness.

#### MPC-Based Internal Controller

Model Predictive Control replaces both voltage and current control loops with a unified optimization-based framework. The MPC algorithm uses a discrete state-space model of the LC filter and inverter to predict system behavior over a finite horizon. At each control step, the algorithm evaluates all possible inverter switching state combinations and selects the one that minimizes a cost function penalizing deviations of the predicted dq-frame currents from their references.

For the GCDCDG system, the prediction horizon is limited to one time step to maintain computational tractability, with the state-space model incorporating the four system state variables: dq-frame filter currents and dq-frame filter capacitor voltages. The cost function directly targets current reference tracking, enabling inherent current limiting without additional outer-loop mechanisms.

MPC achieves the lowest THD among all three controllers — below 1% in all test cases — due to its direct optimization of switching states and inherent ability to exploit system model knowledge. However, its computational demands scale exponentially with horizon length, and its performance is sensitive to model accuracy. These characteristics make MPC the highest-performing but also most demanding option for practical implementation.

#### IV. CRITICAL DISCUSSION AND RESEARCH GAPS

While the reviewed work demonstrates compelling performance improvements from ANN and MPC controllers, several important research gaps and open challenges remain.

##### Stability Analysis of ANN Controllers

A well-recognized limitation of ANN-based control is the absence of rigorous closed-loop stability guarantees. Unlike PI or MPC controllers, where Lyapunov or input-output stability analyses are well-established, ANN controllers are often treated as black boxes. Recent research has begun addressing this gap through Lyapunov-based stability analysis under bounded training conditions, and through establishing stability-preserving boundary conditions during data generation. However, comprehensive stability proofs for ANN controllers in the GCDCDG context remain an open challenge.

##### Robustness to Parameter Uncertainty

Both ANN and MPC controllers assume implicit or explicit knowledge of system parameters. ANN controllers trained on data generated at nominal parameters may exhibit degraded performance when system parameters drift due to component aging or environmental conditions. MPC controllers explicitly depend on the accuracy of the state-space model. Adaptive and robust formulations of both controller types warrant further investigation in the context of GCDCDG applications.

##### Multi-DG Microgrid Operation

The reviewed work focuses on individual GCDCDG operation. However, practical microgrids involve multiple DGs operating in parallel, requiring power sharing coordination. The interactions between the proposed current limiting strategies and multi-DG power sharing dynamics — including circulating currents and frequency/voltage

deviations — represent a rich and largely unexplored research area.

##### Hardware Validation

Simulation results in MATLAB/Simulink, while valuable, require validation on physical hardware setups including real-time digital simulation platforms (e.g., OPAL-RT, dSPACE) and laboratory-scale power hardware. Implementation challenges including quantization effects, computational latency, sensor noise, and real-time operating system constraints may require modifications to the control strategies identified in simulation.

#### V. CONCLUSION

This review has systematically examined the progression of internal control strategies for Grid-Connected Droop-Controlled Distributed Generators, from conventional PI controllers through ANN-based and MPC-based approaches, in conjunction with a novel integrated droop-based power and current limiting strategy. The evidence strongly supports the following conclusions:

The proposed droop-based current limiting strategy eliminates the need for external current limiters while maintaining system stability across diverse abnormal grid conditions including frequency drops, voltage drops, and dynamic load events. ANN-based controllers, trained using PI supervisory data via the LMBP algorithm, consistently outperform PI controllers with approximately 50% THD reduction and 12-24% improvement in dynamic response times, while maintaining comparable computational demands. MPC achieves the highest performance in terms of THD (below 1%) but at significantly greater computational cost, making it less practical for small-scale embedded DG applications. The ANN-based controller thus represents an attractive balance of performance, complexity, and implementation feasibility for practical GCDCDG applications. Future work incorporating MPC-supervised ANN training represents a particularly promising direction for further performance gains.

#### REFERENCES

- [1] Z. Zhang, C. Dou, D. Yue, B. Zhang, S. Xu, T. Hayat, and A. Alsaedi, "An event-triggered secondary control strategy with network delay in islanded microgrids," *IEEE Syst. J.*, vol. 13, no. 2, pp. 1851–1860, Jun. 2019.
- [2] M. E. Meral and D. C. el'ik, "A comprehensive survey on control strategies of distributed generation power systems under normal and abnormal conditions," *Annu. Rev. Control*, vol. 47, pp. 112–132, Jan. 2019.
- [3] Y. Gupta, S. Doolla, K. Chatterjee, and B. C. Pal, "Optimal DG allocation and Volt-Var dispatch for a droop-based microgrid," *IEEE Trans. Smart Grid*, vol. 12, no. 1, pp. 169–181, Jan. 2021.
- [4] N. M. Dehkordi and S. Z. Moussavi, "Distributed resilient adaptive control of islanded microgrids under

- sensor/actuator faults,” *IEEE Trans. Smart Grid*, vol. 11, no. 3, pp. 2699–2708, May 2020.
- [5] Q. Zhong and G. C. Konstantopoulos, “Current-limiting droop control of grid-connected inverters,” *IEEE Trans. Ind. Electron.*, vol. 64, no. 7, pp. 5963–5974, Oct. 2017.
- [6] M. Eskandari and A. V. Savkin, “On the impact of fault ride-through on transient stability of autonomous microgrids: Nonlinear analysis and solution”, *IEEE Trans. Smart Grid*, vol. 12, no. 2, pp. 9991010, Mar. 2021.
- [7] Y. Peng, Z. Shuai, X. Liu, Z. Li, J. M. Guerrero, and Z. J. Shen, “Modeling and stability analysis of inverter-based microgrid under harmonic conditions”, *IEEE Trans. Smart Grid*, vol. 11, no. 2, pp. 13301342, Mar. 2020.
- [8] M. Ganjian-Aboukheili, M. Shahabi, Q. Sha ee, and J. M. Guerrero, “Seamless transition of microgrids operation from grid-connected to islanded mode”, *IEEE Trans. Smart Grid*, vol. 11, no. 3, pp. 21062114, May 2020.
- [9] Y. Geng, L. Zhu, X. Song, K. Wang, and X. Li, “A modified droop control for grid-connected inverters with improved stability in the fluctuation of grid frequency and voltage magnitude”, *IEEE Access*, vol. 7, pp. 7565875669, 2019.
- [10] H. Yazdanpanahi, Y. W. Li, and W. Xu, “A new control strategy to mitigate the impact of inverter-based DGs on protection system”, *IEEE Trans. Smart Grid*, vol. 3, no. 3, pp. 14271436, Sep. 2012.
- [11] D. M. Vilathgamuwa, P. C. Loh, and Y. Li, “Protection of microgrids during utility voltage sags,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp. 1427–1436, Oct. 2006.
- [12] D. C. e’ik and M. E. Meral, “A flexible control strategy with overcurrent limitation in distributed generation systems,” *Int. J. Electr. Power Energy Syst.*, vol. 104, pp. 456–471, Jan. 2019.
- [13] S. Dedeoglu, G. C. Konstantopoulos, and A. G. Paspatis, “Grid-supporting three-phase inverters with inherent root mean square current limitation under balanced grid voltage sags,” *IEEE Trans. Ind. Electron.*, vol. 68, no. 11, pp. 11379–11389, Nov. 2021.
- [14] H. J. Laaksonen, “Protection principles for future microgrids,” *IEEE Trans. Power Electron.*, vol. 25, no. 12, pp. 2910–2918, Dec. 2010.
- [15] X. Guo, W. Liu, X. Zhang, X. Sun, Z. Lu, and J. M. Guerrero, “Flexible control strategy for grid-connected inverter under unbalanced grid faults without PLL,” *IEEE Trans. Power Electron.*, vol. 30, no. 4, pp. 1773–1778, Apr. 2015.
- [16] Z. Chen, X. Pei, M. Yang, L. Peng, and P. Shi, “A novel protection scheme for inverter- interfaced microgrid (IIM) operated in islanded mode,” *IEEE Trans. Power Electron.*, vol. 33, no. 9, pp. 7684–7697, Sep. 2018.
- [17] I. Sadeghkhani, M. E. H. Golshan, J. M. Guerrero, and A. Mehrizi-Sani, “A current limiting strategy to improve fault ride-through of inverter interfaced autonomous microgrids,” *IEEE Trans. Smart Grid*, vol. 8, no. 5, pp. 2138–2148, Sep. 2017.
- [18] L. Zhou, A. Swain, and A. Ukil, “Reinforcement learning controllers for enhancement of low voltage ride through capability in hybrid power systems,” *IEEE Trans. Ind. Informat.*, vol. 16, no. 8, pp. 5023–5031, Aug. 2020.
- [19] Y. Jiang, X. Li, C. Qin, X. Xing, and Z. Chen, “Improved particle swarm optimization based selective harmonic elimination and neutral point balance control for three-level inverter in low-voltage ride-through operation,” *IEEE Trans. Ind. Informat.*, vol. 18, no. 1, pp. 642–652, Jan. 2022.
- [20] J. Rocabert, A. Luna, F. Blaabjerg, and P. Rodr’iguez, “Control of power converters in AC microgrids”, *IEEE Trans. Power Electron.*, vol. 27, no. 11, pp. 47344749, Nov. 2012.