# Time Disciplined Non-PLL Active Synchronization for Grid Forming Inverters

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# Project Breakdown

1. Grid Forming Inverters (GFMIs) [1]
   - Critical to providing stability for weak systems (high percent GFLI, microgrids, …).
2. Active Synchronization [2]
   - With a DQ inverter, we can separate voltage and phase.
   - Phase is the key to synchronization.
3. Non-PLL [3] (Phase-Lock Loop)
   - PLLs are inaccurate in weak grids and computationally burdensome.
   - Solution is relying entirely on the internal clock and not the grid.
4. Time Disciplined [4]
   - With a reliance on phase, we need to have a solid phase reference.

# Metrics from Existing Standards

TABLE I
IEEE 1547 RELEVANT METRICS [5]

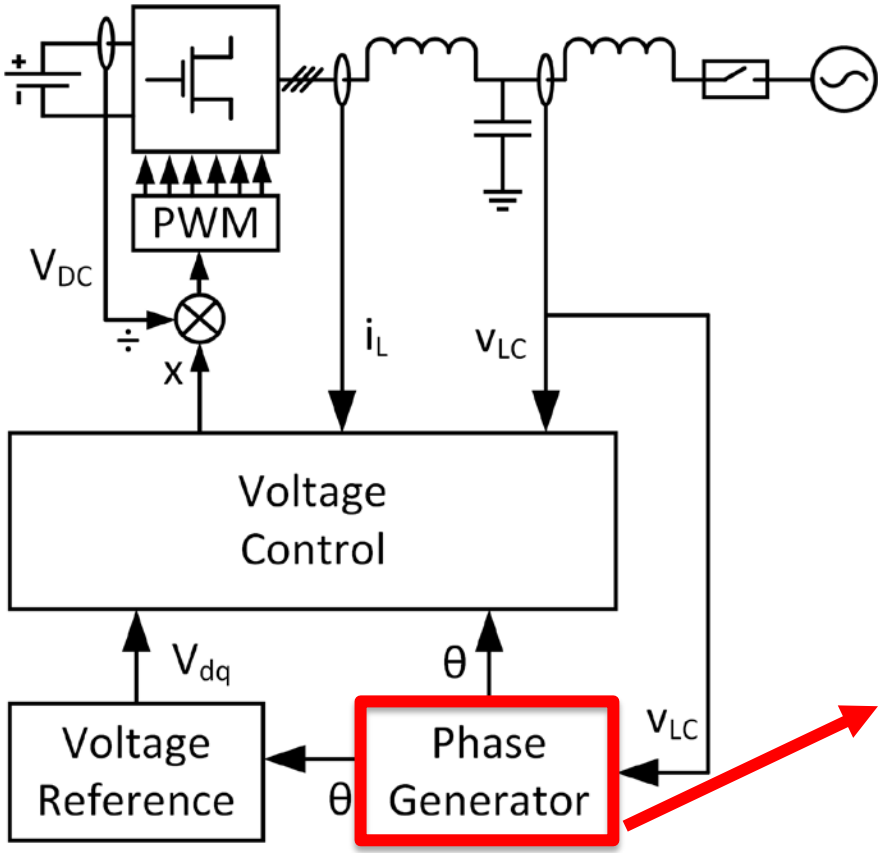
| Requirement | Limit | Section of IEEE 1547-2018 |
|---|---|---|
| Absolute Voltage | 0.7 - 1.1 PU | 6.4 |
| Absolute Frequency | 58.5 - 61.2 Hz | 6.5 |
| ROCOF (Ride Through) | 0.5 Hz/sec | 6.5.2.5 |
| Enter Service | 0.917 - 1.05 PU Voltage<br>59.5 - 60.1 Hz | 4.10.2 |
| Reconnection Tolerances (with respect to the Grid) | 0.1 Hz Frequency (59.9 - 60.1 Hz)<br>3% PU Voltage<br>10° phase | 4.10.4 |
| Initial Grid Synchronization | Maximum EPS Line Voltage<br>138% for <1 cycle | 7.4 |

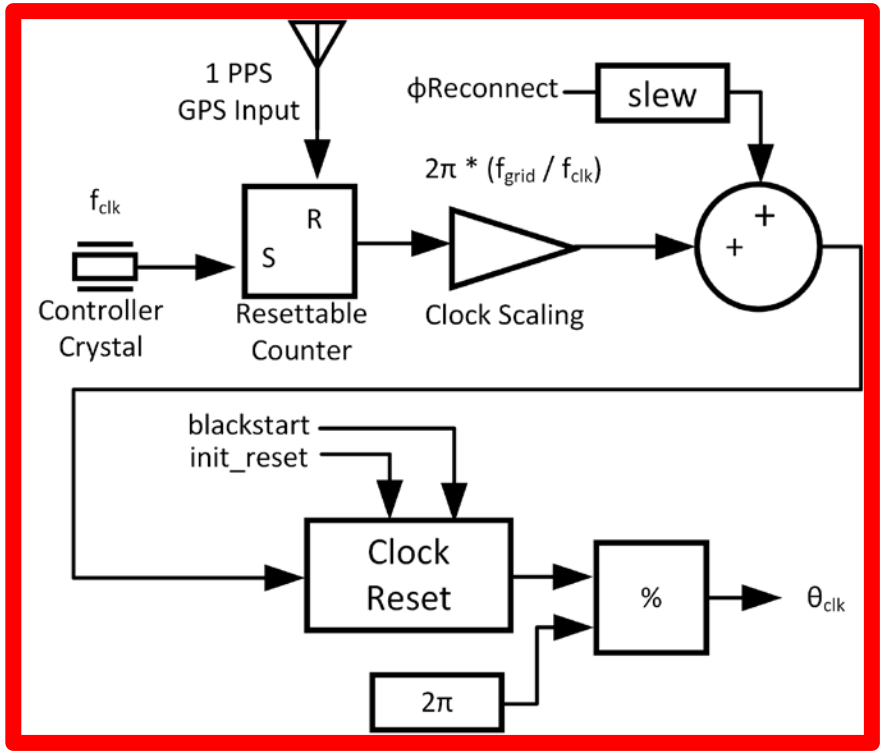
TABLE II
IEEE 1547.4 MODE COMPARISON [6]

| Framework Mode | IEEE 1547.4-2011 Mode | Section of IEEE 1547.4-2011 |
|---|---|---|
| Reconnection Coordination | Reconnection Mode | 4.4.4 |
| Ride Through | Area EPS-connected Mode (normal parallel operation) | 4.4.4 |
| | Transition-to-Island Mode | 4.4.2 |
| | Island Mode | 4.4.3 |

# Synchronization Modes

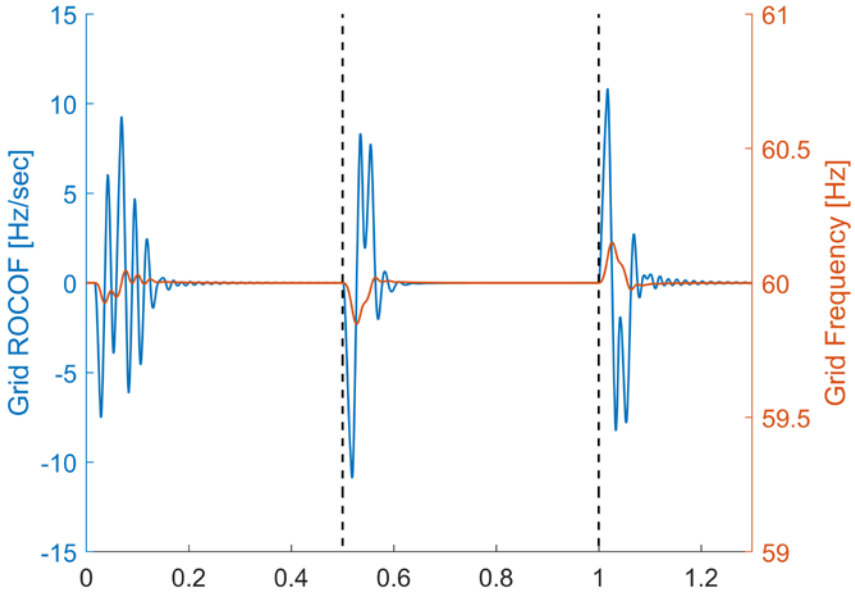
# Inverter Model



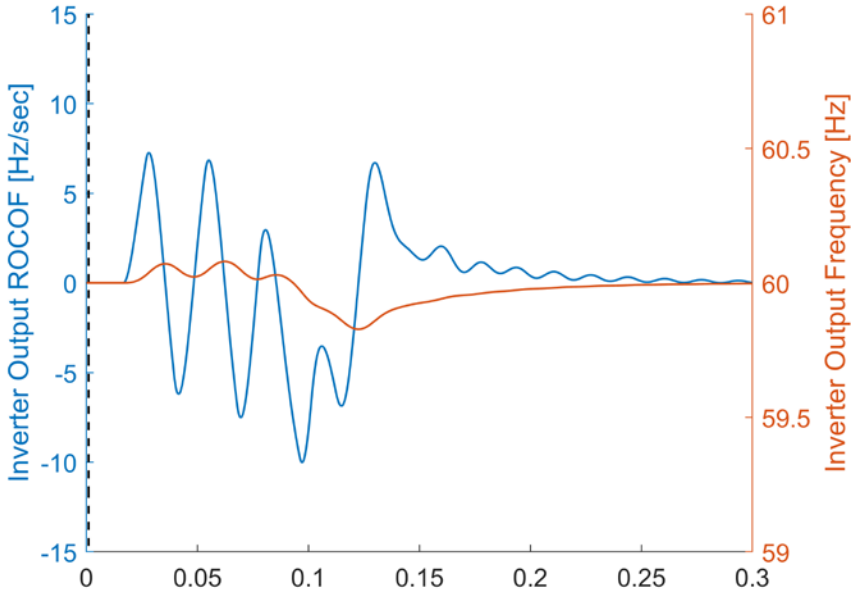



# Simulation Results – Frequency/ROCOF

Initialization, Islanding, Reconnection (Grid)




Blackstart (Inverter)



# Simulation Results – Summary Table

TABLE IV
SIMULATION RESULTS SUMMARY

| Category/Measurement | Min Frequency [Hz] | Max Frequency [Hz] | Min ROCOF [Hz/sec] | Max ROCOF [Hz/sec] |
|---|---|---|---|---|
| Initialization (Inverter) | 59.79 | 60.18 | -12.81 | 11.13 |
| Initialization (Grid) | 59.92 | 60.05 | -7.523 | 9.278 |
| Ride Through (Inverter) | 59.56 | 60.01 | -12.51 | 13.04 |
| Ride Through (Grid) | 59.85 | 60.02 | -10.89 | 8.336 |
| Reconnection (Inverter) | 59.94 | 60.38 | -13.02 | 12.52 |
| Reconnection (Grid) | 59.97 | 60.15 | -8.252 | 10.85 |
| Blackstart (Inverter) | 59.83 | 60.08 | -9.996 | 7.26 |

# References


[1] P. Denholm, T. Mai, B. Kroposki, R. Kenyon, and M. O'Malley, Inertia and the Power Grid: A Guide Without the Spin. No. NREL/TP-6A20-73856, National Renewable Energy Laboratory, Golden, CO, May 2020.

[2] J. Wang, A. Pratt, and M. Baggu, "Integrated synchronization control of grid-forming inverters for smooth microgrid transition," in 2019 IEEE Power and Energy Society General Meeting (IEEE PES GM), pp. 1–5, Aug. 2019.

[3] J. Wang, B. Lundstrom, and A. Bernstein, "Design of a non-pll grid forming inverter for smooth microgrid transition operation," in 2020 IEEE Power and Energy Society General Meeting (IEEE PES GM), Aug. 2020.

[4] M. S. Golsorkhi, M. Savaghebi, D. D. Lu, J. M. Guerrero, and J. C. Vasquez, "A GPS-based control framework for accurate current sharing and power quality improvement in microgrids," in IEEE Transactions on Power Electronics, vol. 32, pp. 5675–5687, July 2017.

[5] "IEEE standard for interconnection and interoperability of distributed energy resources with associated electric power systems interfaces," IEEE Std. 1547-2018, Apr. 2018.

[6] "IEEE guide for design, operation, and integration of distributed resource island systems with electric power systems," IEEE Std. 1547.4-2011, July 2011.

# Thank You

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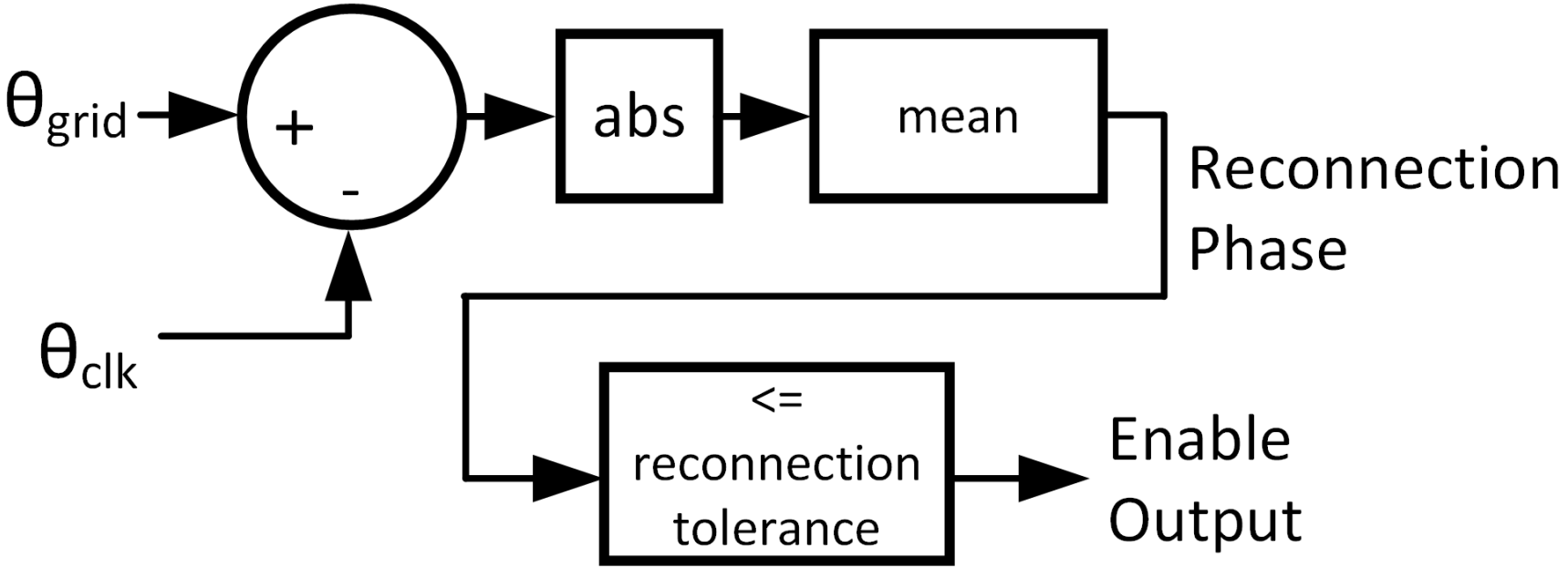
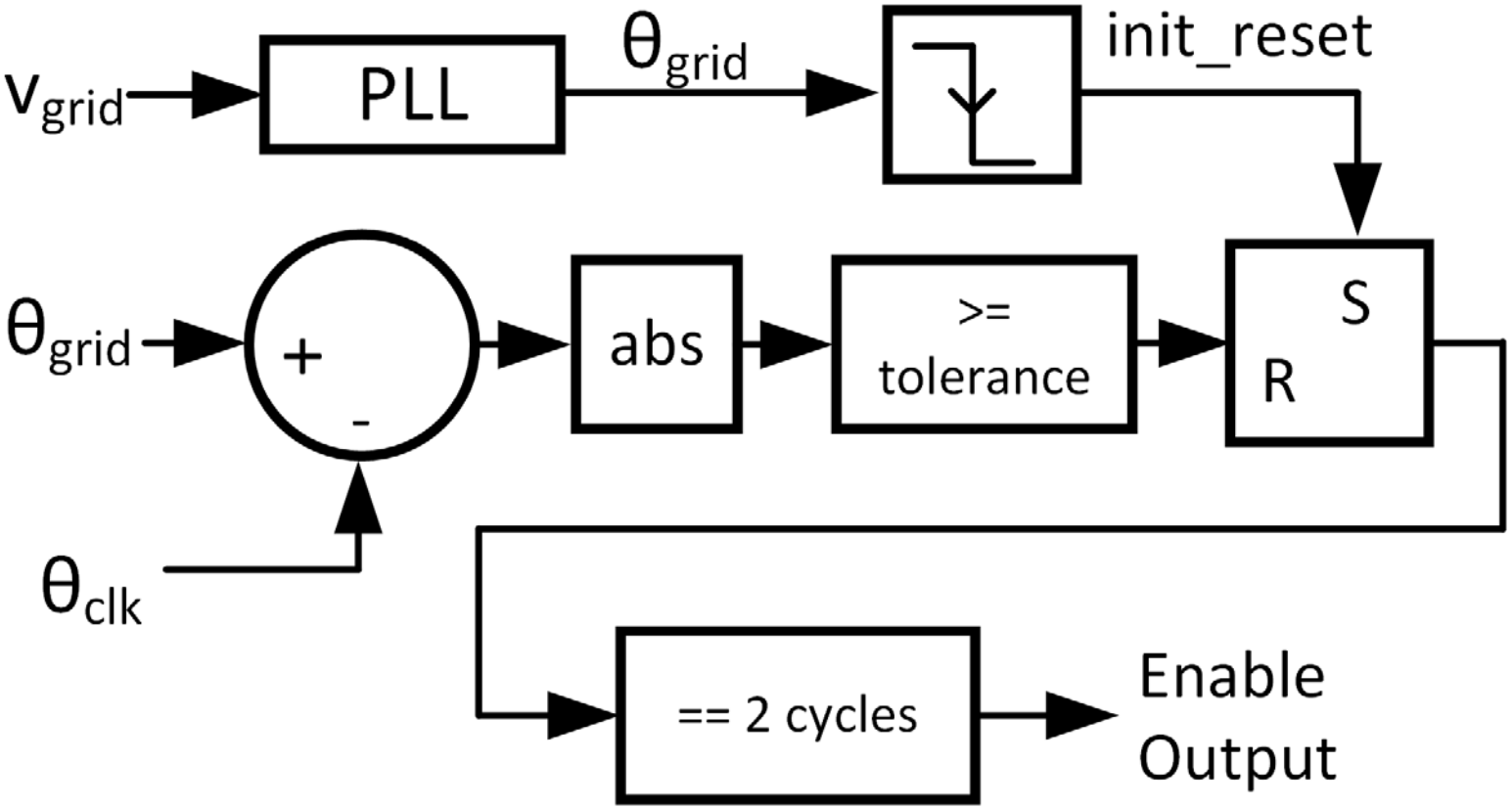
# Backup Slides

# Initialization Phase Generator

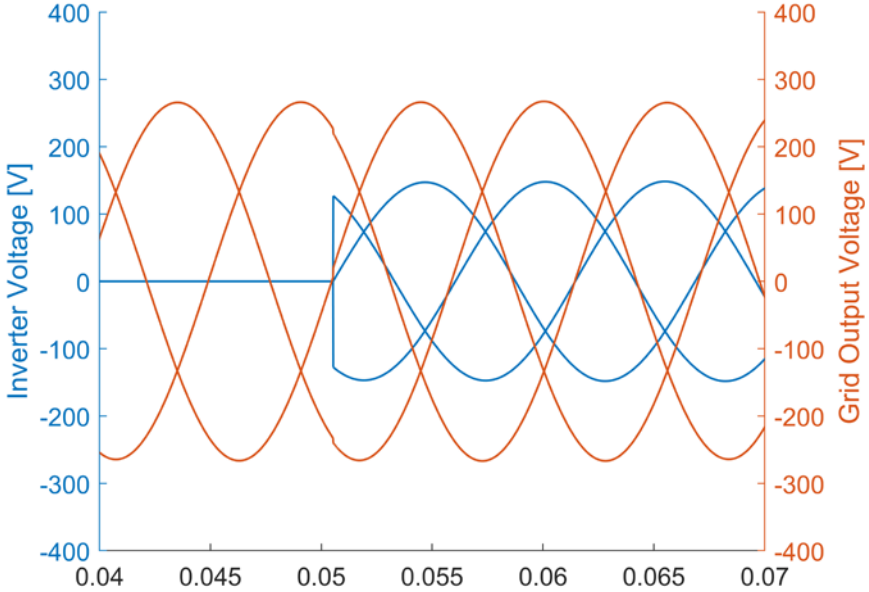


# Reconnection Phase Generator

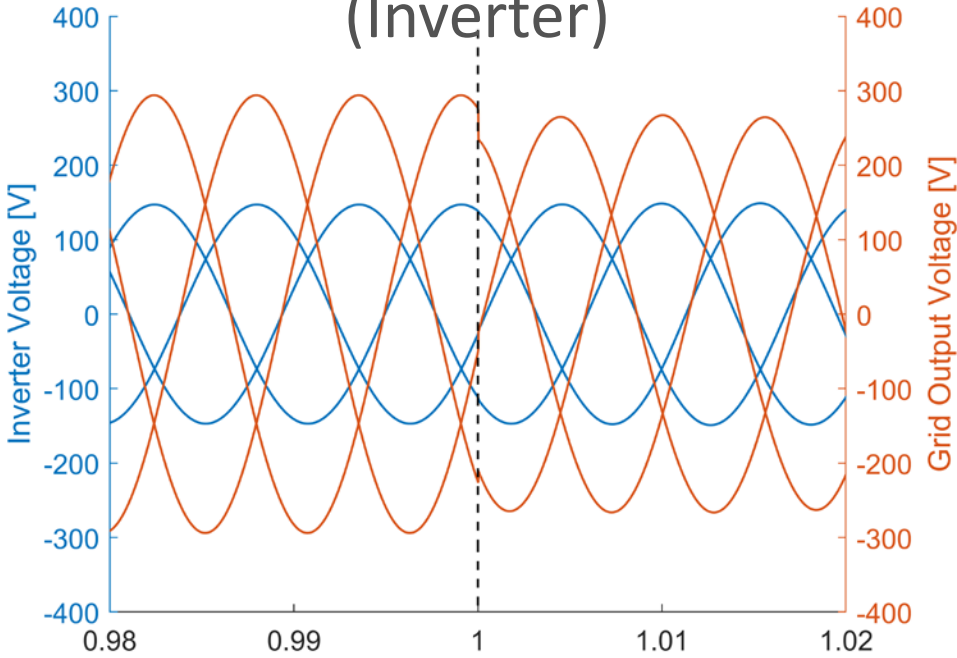


# Simulation Results - Voltages

## Initialization (Inverter)

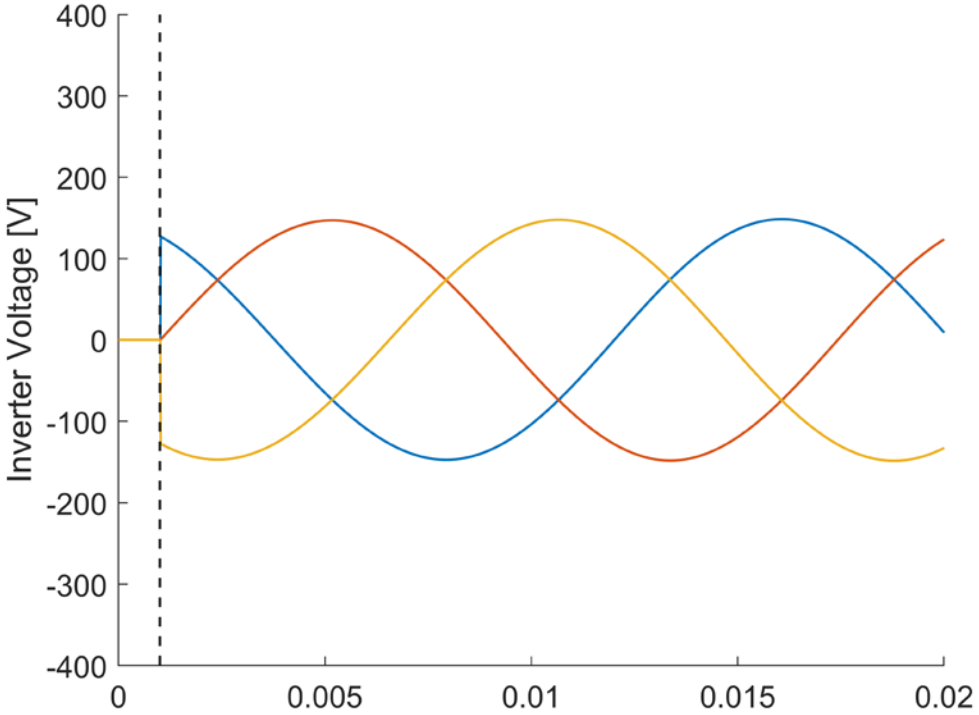



## Reconnection (Inverter)



# Simulation Results – Voltages (Cont.)

Blackstart
(Inverter)



# Simulation Results – Frequency (Inverter)

## Initialization, Islanding, Reconnection (Inverter)