Large-Scale Adoption of Self Synchronized Universal Droop Controller-Based Inverters to Enable Ancillary Services for Different Modes of Distribution System Operations

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Using the self-synchronized universal droop controller, the ancillary services are enabled to sharply increase the use of solar power.

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INTRODUCTION

- A self-synchronized synchronous converter does not use a dedicated synchronization unit; instead, it performs the synchronization operation internally [1], [2].
- This model involves droop coefficients which are set in such a way that a 100% increase of real power results in a 10% decrease of voltage, and a 100% increase of reactive power results in a 1% increase of the frequency.

RESEARCH QUESTION & OBJECTIVES

- This study seeks to enable ancillary services for different modes of distribution system operations via large-scale adoption of self-synchronized universal droop controller-based inverters.
- The objectives for ancillary services are a frequency range of ±0.5%, a voltage range of ±5%, and black start capabilities within 1s with voltage overshoot less than 5%. Under this conditions, the system operators rely on a few units, called black start units, that can start independently [3], [4].

METHODOLOGY

- A 300-node system was modeled using the IEEE 123 bus test feeder on a real-time power system simulator.
- The distribution system operates at a nominal voltage of 4.16 kV and consists of fifteen node cells with 3-phase, 2-phase, and single-phase lines. Fifteen switches were used to reconfigure the system and operate as multiple islands.
- The model operated with a total load equivalent to 3.5 MW and 1.92 MVA. The model was validated using OpenDSS as a benchmark.
- The voltage results of all the nodes by simulating the distribution system on OpenDSS was compared to the voltage results of all the nodes by simulating the distribution.
- The percent error was compared for each node cell as:

$$\%\text{Relative Error} = \frac{OpenDSS - Hypersim}{OpenDSS} \times 100 \quad (1)$$

- From the results, it can be observed that the percent errors for the voltages are all within 1%. This confirmed the successful modeling of the IEEE 123 bus system in real-time to perform simulations.

REAL-TIME SIMULATION RESULTS

Grid-connected mode to islanded mode
Time: 0 to 10 seconds
Pset = 0.08 p.u. and Qset = -0.06 p.u.

- At time t=3 sec for 1st set of inverters
- At time t=4 sec for 2nd set of inverters
- At time t=5 sec for 3rd set of inverters
- At time t=6 sec for 4th set of inverters
- At time t=7 sec for 5th set of inverters

Islanded Mode:
Time: 10 to 14 seconds
- At time t=10 sec, system Islanded by opening substation circuit breaker.

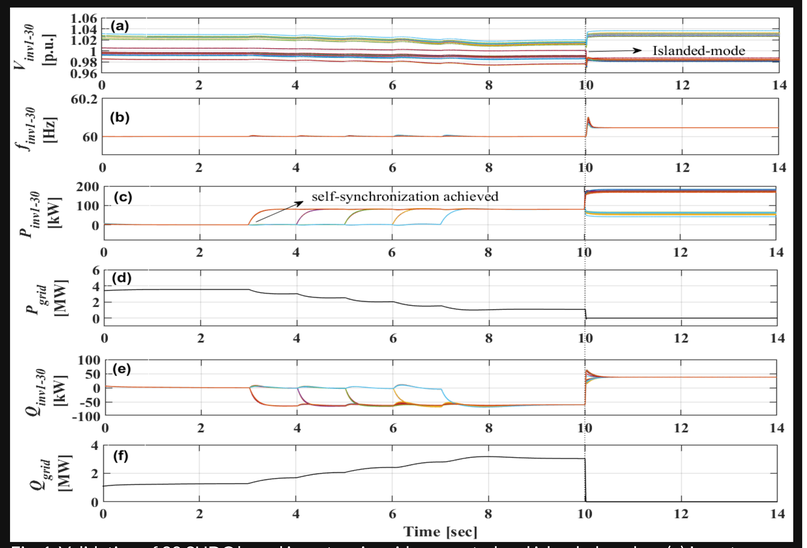

Fig. 1 Validation of 30 SUDC based inverters in grid-connected and islanded modes: (a) Inverter Voltages, (b) System Frequency, (c) Inverter Active Powers, (d) AC Source Active Power, (e) Inverter Reactive Powers, and (f) AC Source Reactive Power

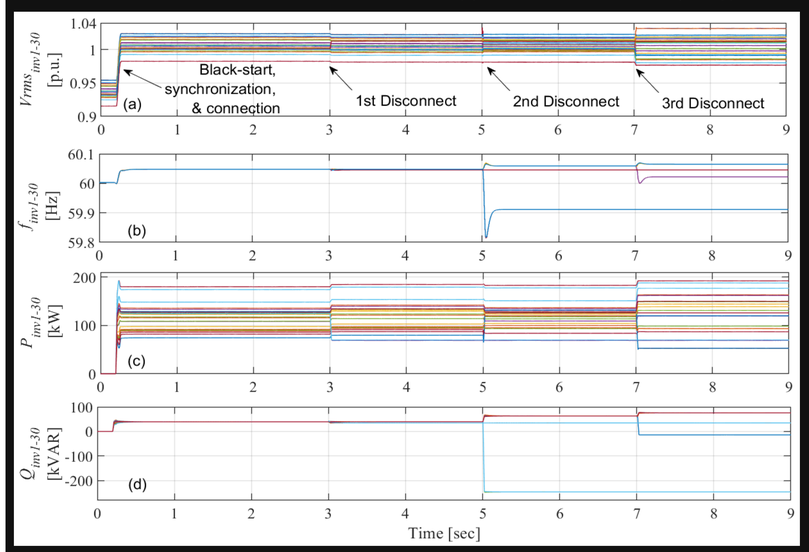

Fig. 2 Validation of black-start capabilities of 30 SUDC based inverters in islanded mode: (a) Inverter Voltages, (b) System Frequency, (c) Inverter Active Powers, and (d) Inverter Reactive Powers.

Black-start and grid-forming
- At time t=0.2 sec, inverters are black-started, synchronized and connected.
- At t = 3 sec, 1st Disconnect: Sectionalizer S4 opened, Node cells 4 and 13 islanded.
- At t = 5 sec 2nd Disconnect: Sectionalizer S8 opened, Node cell 8 islanded.
- At t = 7 sec 3rd Disconnect: Sectionalizers S9 and S15 opened, Node cells 9 and 12 islanded.

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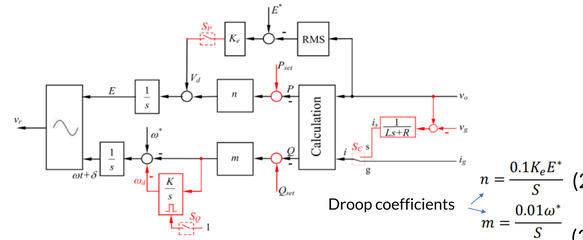
DISCUSSION

- Synchronization happens only once during the start to connect inverters to the grid. Every time the inverter operation is changed, it can be called regulation.



$$n = \frac{0.1K_gE^*}{S} \quad (2)$$

$$m = \frac{0.01\omega^*}{S} \quad (3)$$

Fig. 3 The self-synchronized universal droop control (SUDC)

- A study of load in each node cell to operates in the standalone mode was analyzed. The three-phase apparent power load capacity, $S_{3\varphi}$ of each node cell can be calculated as:

$$S_{3\varphi} = \sqrt{(P_a + P_b + P_c)^2 + (Q_a + Q_b + Q_c)^2} \quad (4)$$

- The grid-forming and grid-feeding inverters connected in different nodes are shown in Fig. 4.

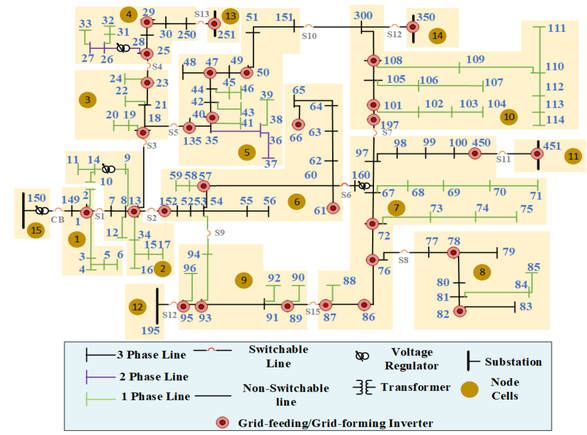


Fig. 4 IEEE 123-bus testbed with 30 grid-feeding/forming inverters

CONCLUSIONS

- This research demonstrated the regulations were performed within the given ranges, i.e., less than 5% for voltage and less than 0.5% for frequency, in grid-connected and islanded modes.
- This study shows the performance of SUDC based inverters in achieving black start within 1 sec without any voltage overshoot.
- The black start functionality applies to the SUDC inverters cold-load pickups, when there are multiple faults in different locations during blackouts and extreme weather events.

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