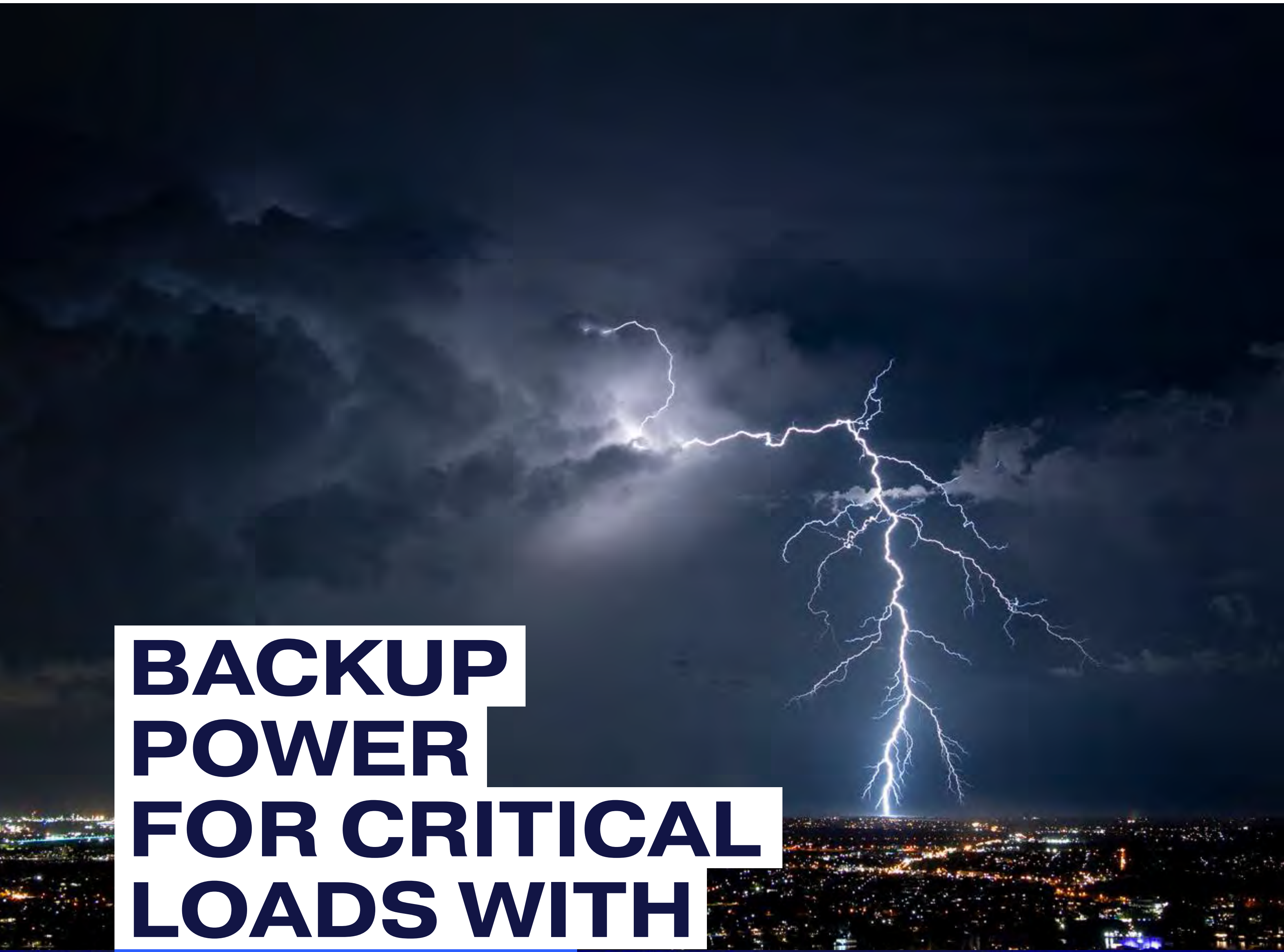
POWERING A CLEANER PLANET™



BACKUP POWER FOR CRITICAL LOADS WITH DYNAMIC TRANSFER

Introduction

This paper compares two strategies for providing backup power to large commercial and industrial facilities — traditional double-conversion uninterruptible power supplies (UPS) and battery energy storage systems with Dynapower's patented Dynamic Transfer technology.

While there are advantages and disadvantages to both approaches, for all but the most sensitive of critical loads, Dynamic Transfer may represent a better value proposition than commercially available double-conversion UPS's.

Double Conversion UPS Overview

The traditional double conversion UPS system consists of a front-end charging rectifier, a battery, and an output inverter which directly services the critical load (see Figure 1). The load is continuously supported by the inverter, so there is no loss of service when the load is disconnected from the grid. When disconnected from the grid, the inverter draws energy from the battery instead. Similarly, there is no interruption of service upon the return of utility service and the battery will begin to recharge.

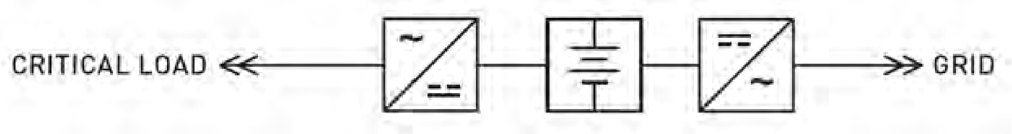


Figure 1 –Traditional UPS Configuration

Traditional UPS Disadvantages

- **High System Losses.** All facility power flows through a rectifier and inverter, so large losses are incurred when the UPS is engaged. Depending on UPS efficiency, this may represent a 5% or greater increase in overall facility power and energy consumption. For large loads, this results in high operating costs (that are not always properly considered).
- **One-Way Power Flow.** The battery cannot be charged from any on-site renewable generation or deployed for any other purpose than back up power. Both limitations prohibit other potential savings and/or revenues that can dramatically reduce all-in operating cost of a large scale battery system.
- **Short Duration / Infrequent Cycling.** UPS batteries are generally intended for very short duration backup (measured in minutes) and very few cycles per year. More frequent usage will cause significant battery capacity degradation and may necessitate periodic battery replacement, which represents a large portion of system cost.
- **Limited Power Range.** Facility scale UPS's are generally unavailable above 1.2MVA.

Traditional UPS Advantages

- Truly seamless transition to back up power.
- Potentially lower up-front cost.
- Filtration from grid can help correct for voltage harmonic distortion on the grid.

Dynamic Transfer Overview

Dynapower's patented Dynamic Transfer technology utilizes a bi-directional utility-interactive inverter and battery configured to create a shunt-connected uninterruptible power supply (UPS) which provides reliable backup power to critical loads (see Figure 2). The inverter autonomously, and generally seamlessly, transitions from grid-tied operation to microgrid mode. The inverter also manages the seamless transition back to grid tied upon return of utility service.

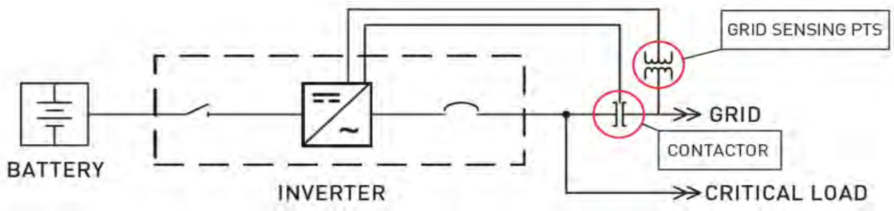


Figure 2 –Typical Dynamic Transfer Configuration

Dynamic Transfer Advantages

- **Low System Losses.** Facility power from the utility does not flow through inverter or battery and inverter losses are only incurred when the system is in active use (less aux losses).
- **Bi-Directional Power Flow.**
  - Battery can be charged from renewables or other on-site generation, facilitating energy time-shifting, self-consumption of PV, and extending the effective duration of battery by prioritizing renewable consumption over battery energy consumption in microgrid mode.
  - Battery can discharge to the grid, faciliting peak shaving to reduce demand charges, energy arbitrage, and a host of ancillary grid services that can generate revenue.
  - **Thus, independent of the benefits of backup power, the system can be considered an *investment* with an expected pay-back, as opposed to a sunk capital equipment cost.**
- **Longer Duration / High Cycling.** Stationary energy storage batteries are intended for longer duration (measured in hours) and medium to very high cycling applications.
- **Scalable.** Can be utilized at commercial scale or multiple BESS's can be connected for utility scale backup power.
- **Grid Support Functions.**
  - Power factor correction for facility.
  - Voltage and frequency support modes to help reduce instances of transition to microgrid mode.
- **Reduced Costs with PV.** When installed in conjunction with a PV system, Income Tax Credits (ITC) and accelerated depreciation schedules can substantially reduce system cost.

Dynamic Transfer Disadvantages

- Seamless transition to back up power in most grid fault conditions, but in some instances, there will be a very brief (millisecond) interruption of grid voltage. This is addressed at length later.
- Potentially higher up-front cost.
- Minimal filtration from grid, so if the utility feed is heavily distorted, this will be experienced by the critical load. The inverter cannot correct grid voltage harmonic distortion.

Dynamic Transfer Functional Overview

Adjustable Voltage/Frequency “Disconnect” Settings

The inverter and critical load are grid-tied under normal grid conditions. The inverter constantly monitors the upstream grid voltage and frequency via the grid-sensing potential transformers (PT’s) (shown in Figure 2). The inverter has user-settable voltage and frequency “trip levels” and an associated ride-through timer for each range. These are shown in Figures 3 & 4 below. These settings are adjusted as appropriate for the site condition and specific use-case.

REGIONS	SYSTEM DEFAULT SETTINGS	SYSTEM DEFAULT	RANGE OF ADJUSTABILITY	RANGE OF CLEARING TIME(S)
Over-voltage level 3	>=120	16ms	fixed 120	0.
Over-voltage level 2	115<V<120	1	102-	0
Over-voltage level 1	110<V<=115	1	102-	0
Normal operation	88<=V<=110	NA	NA	NA
Under-voltage level 1	70<=V<88	2	75	0
Under-voltage level 2	50<=V<70	2	5	0
Under-voltage level 3	V<50	0.16	Fixed 50	0

Figure 3 – AC Voltage Protective Settings

REGIONS	SYSTEM	SYSTEM TIME	RANGE OF ADJUSTABILITY	RANGE OF CLEARING TIME
Over-frequency 3	>62	0.16	60.1 –	Fixed 0.16
Over-frequency 2	>62	0.16	60.1 – 67.5	0
Over-frequency 1	60.5<f<=62	0.16	60.1 – 6	0
Normal operation	59.5<=f<=60.5	NA	NA	NA
Under-frequency 1	57<=f<59.5	2	5	0
Under-frequency 2	f<57	0.16	5	0
Under-frequency 3	f<57	0.16	52.5 - 59.9	Fixed 0.16

Figure 4 – AC Frequency Protective Settings

Steady State Grid-Tied Operation

The grid is stable and in valid bounds, the grid disconnect device is closed, and the inverter is in grid-tied (PQ) mode. The batteries can be charged from the grid or by renewables. The battery is available to provide ancillary services (peak shaving, energy arbitrage, capacity market participation, etc.). Assuming backup power is a priority, some portion of battery capacity is reserved for emergency backup use.

Grid-Tied to Microgrid (PQ to UF) Transition

When a grid disturbance is detected, in the form of a violation of voltage/frequency "disconnect" settings, the inverter will execute a Dynamic Transfer to microgrid mode. The inverter commands the grid disconnect device to open and transitions to Microgrid mode. By opening the grid disconnect, the inverter has isolated itself and the critical loads from the grid. This operation is considered 'intentional islanding'. The realized transition time has multiple variables that are addressed in depth in a later section.

Steady State Microgrid Operation

Once the system is in Microgrid mode, the inverter behaves as the grid by providing clean, reliable power to the critical load. If there are other generating assets onsite (solar, wind, etc) the inverter will automatically prioritize the use of renewables over battery export. If renewable energy production exceeds the critical load, the inverter will charge the batteries with the surplus energy. The inverter continues to monitor the utility voltage feed via the grid sensing PT's to determine when the grid has returned to a normal state.

Microgrid to Grid-Tied (UF to PQ) Transition

Upon return of the grid to valid voltage frequency bounds, the inverter will begin a 'Grid OK' countdown timer. This timer is to verify that the grid is truly back and to ensure the system does not transition back to the grid prematurely. The factory default is 5 minutes, but this is user-adjustable. Upon satisfaction of the 'Grid OK' timer, the inverter will synchronize the microgrid to the utility. This means the microgrid voltage is matched to the grid voltage's magnitude and phase angle. Once synchronized, the inverter will command the grid disconnect to close, thus restoring utility service to the critical load with no interruption of service. This transition is transparent to the load. The inverter then switches back to PQ mode to resume grid-tied operations.

Dynamic Transfer Timing

Grid-tied to Microgrid Transition (PQ to UF)

There are multiple variables that impact total transfer time. The variables which have the largest impact on the transfer time tend to be external to the Dynapower system — namely, the grid disconnect open time, the facility inrush current characteristics, and the worst-case fault type.

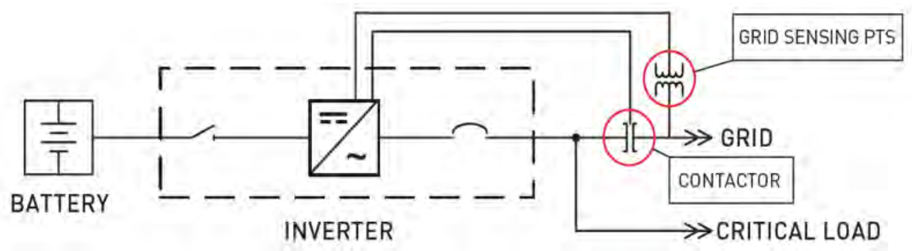


Figure 5 –Typical Dynamic Transfer Configuration

As shown in Figure 5, the inverter cannot be in full control of the AC bus until the grid disconnect device is opened, which isolates the inverter from the faulted grid. Thus, the contactor open time is a limiting factor in how quickly the system transitions. This constraint generally only matters in the scenario of a low-impedance grid fault, where one or more phases are shorted together. Because this generally represents a worst-case transition time, this is where Dynamic Transfer time estimations focus. If it is deemed that a facility will "ride-through" this worst-case event satisfactorily, then all other cases are covered.

The sequence of events and associated duration ranges are:

1) **V/F excursion detection time** – this is the time for the inverter to detect that the grid has gone out of bounds. The timing of this is varies with fault type. A severe grid disturbance will be detected more quickly than a minor disturbance, and a three-phase fault will be detected more quickly than a single-phase fault. Typical ranges for detection time are **2 to 24ms**.
2) **V/F timer expiration** – this is a user-setting and can be set as **fast as 1ms** for severe undervoltage ranges.
3) **Grid disconnect 'Open' command** – this is the time it takes for the inverter to toggle digital output to command disconnect to open. **5-10ms**
4) **Isolation Device Open time** – this represents the mechanical opening time of the contactor/breaker. This is one of the largest variables in the analysis and is external to the Dynapower system. Thus, review of specification of the disconnect device(s) under consideration is required. Typical values might be:
    - AC contactor – **75-150ms**
    - Motorized AC circuit breaker – **100-200ms**
    - Vacuum Breaker – **35-75ms**
    - Static disconnect switch -**8-16ms**
5) **PQ/UF transition** – **1-2ms**
6) **Ramp to nominal voltage** – this varies with magnitude of voltage drop and load inrush current profile. For relatively benign 'voltage sags' this recovery can is very rapid. For more extreme events where voltage decays very low or to zero, this recovery time is greater. This is on the order of **4ms to 80ms**.

To estimate expected transfer times, information on the breaker to be utilized, load characteristics, and inrush current characteristics is required. Ideally, system energization current and power measurements would be available to quantify load inrush current. This can be measured by energizing the full load while monitoring with a high-resolution power quality analyzer. If detailed load information is not available, Dynapower can provide some budgetary guidance of what reasonable assumptions might be in a specific case.

SAMPLE SCENARIOS

SEQUENCE	TIME (MS)
Fault	3
V/F ride through	1
Open command digital output	5
Grid disconnect open time	30
PQ to UF transition	1
UF recovery to nominal	50
Total time (V/F violation to nominal microgrid)	**90**

Figure 6 – Sample scenario, low-impedance fault with MV vacuum breaker. All values indicative.

SEQUENCE	TIME (MS)
Fault	16
V/F ride through	1
Open command digital output	5
Grid disconnect open time	35
PQ to UF transition	1
UF recovery to nominal	7
Total time (V/F violation to nominal microgrid)	**65**

Figure 7 – Sample scenario, voltage sag with MV vacuum breaker. All values indicative.

Case Study - Dynamic Transfer (PQ to UF)

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Dynapower's CPS-1500 with Dynamic Transfer was deployed to provide backup power to a 1.5MW industrial facility with sensitive critical loads. The facility suffered significant power quality issues that were causing expensive loss of production, excessive material scrap, and personnel downtime during (and recovering from) outages. The screenshots below are high-resolution electrical waveforms extracted from the CPS-1500. **This is real-world data; not a simulation and not laboratory conditions.**

Site Conditions:

- 1.5MVA max industrial facility
- Medium voltage vacuum breaker with an open time delay of 35-40ms.
- UV trip settings: ≤ 90% voltage for more than 5ms.
- Breaker with undervoltage coil to automatically trip breaker in grid loss scenario (if faster than CPS detection).

CASE 1

Line to Line Grid Fault Recovery

This is among the worst-case faults.

Trace Definitions: Red = Vab, Yellow = Vbc, Blue = Vca

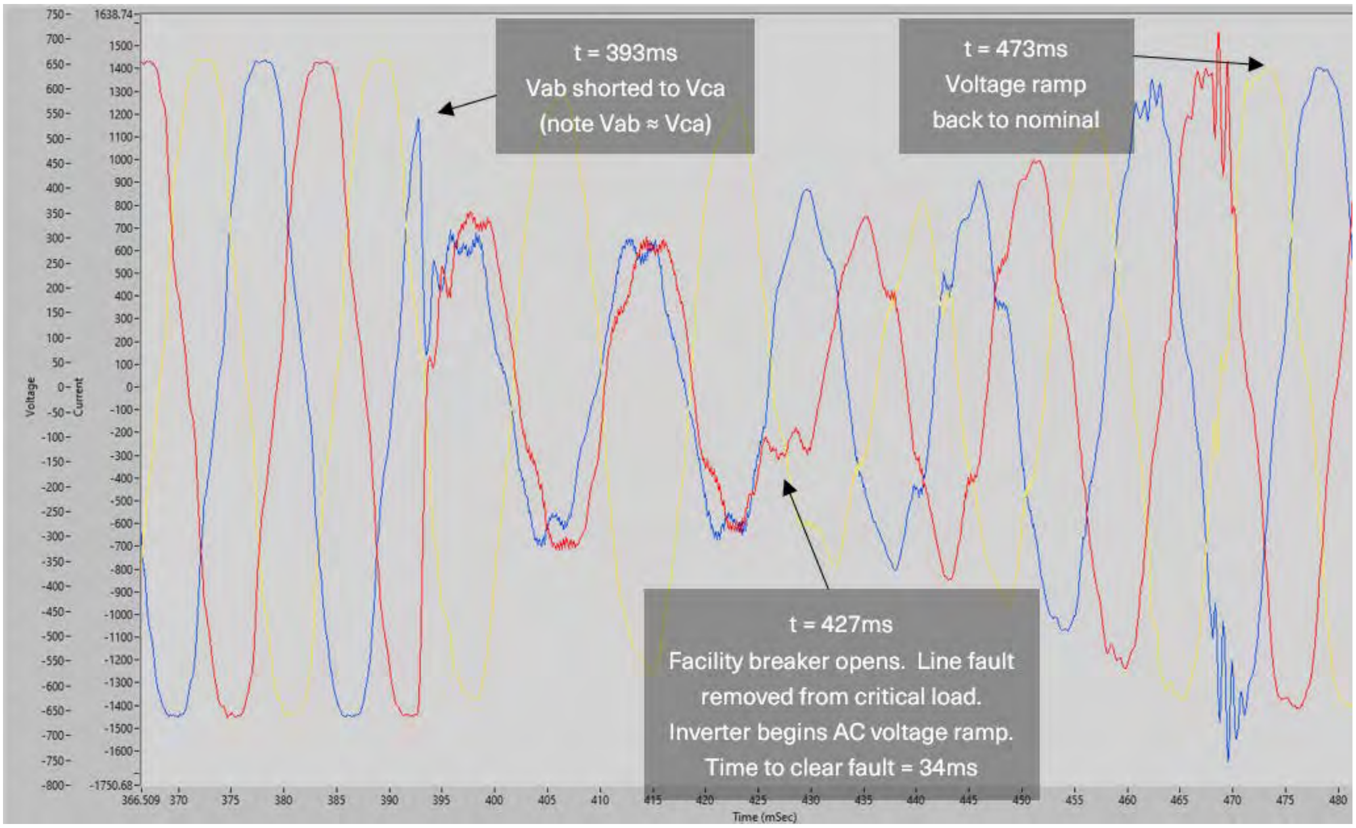

Figure 8 – AC Voltage waveforms, critical load recovery from Line to Line short on utility feed.

Trace Definitions: Light Blue = Ia, Orange = Ib, Dark Blue = Ic, Red = Vab

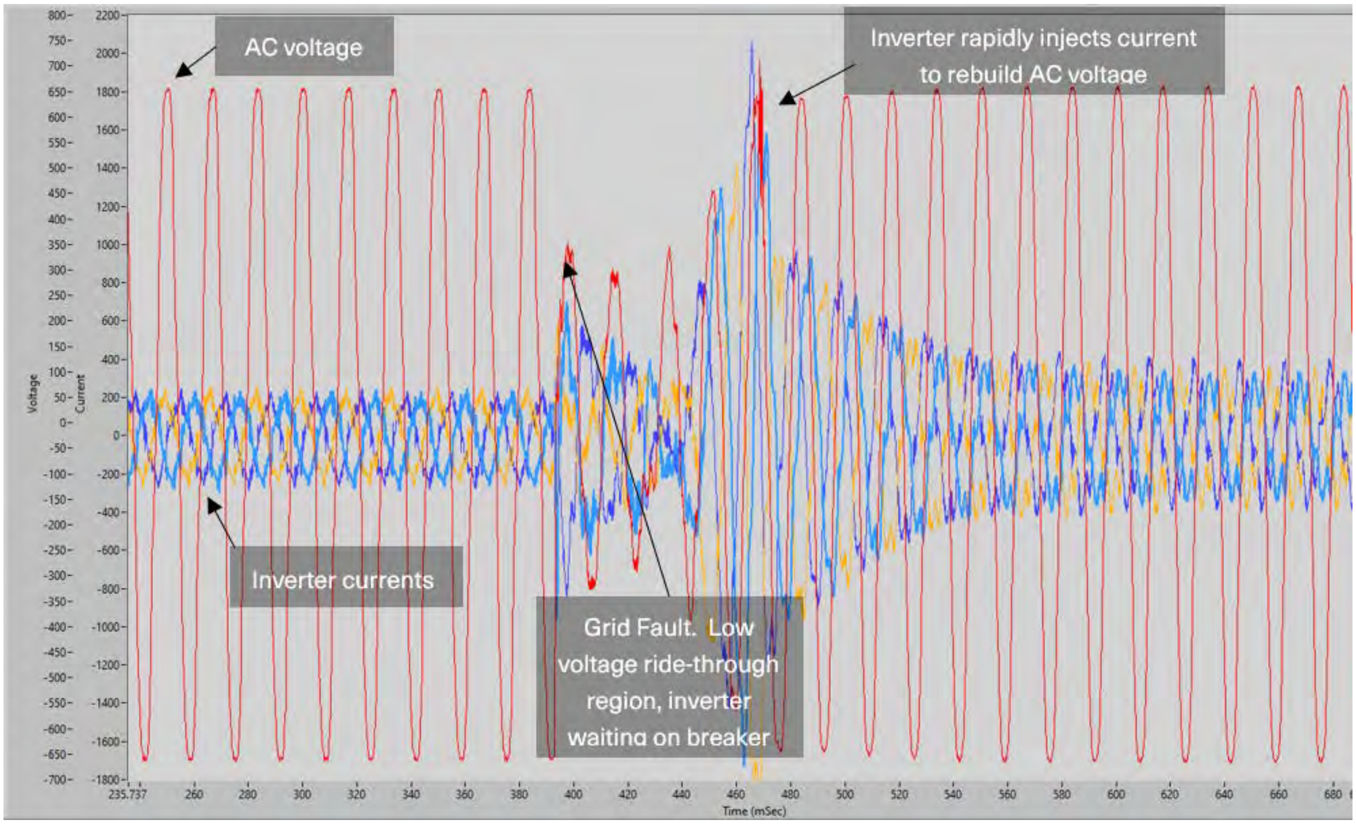

Figure 9 – AC Current waveforms, critical load recovery from Line to Line short on utility feed.

Total transfer time in this instance is **~0.080 second**, from grid fault initiation to restoration of nominal voltage. The critical load was successfully isolated from loss of phase and operations continued unabated.

CASE 2

Three-Phase Voltage Sag to Below 85% of Nominal

Trace Definitions: Red = Vab, Yellow = Vbc, Blue = Vca

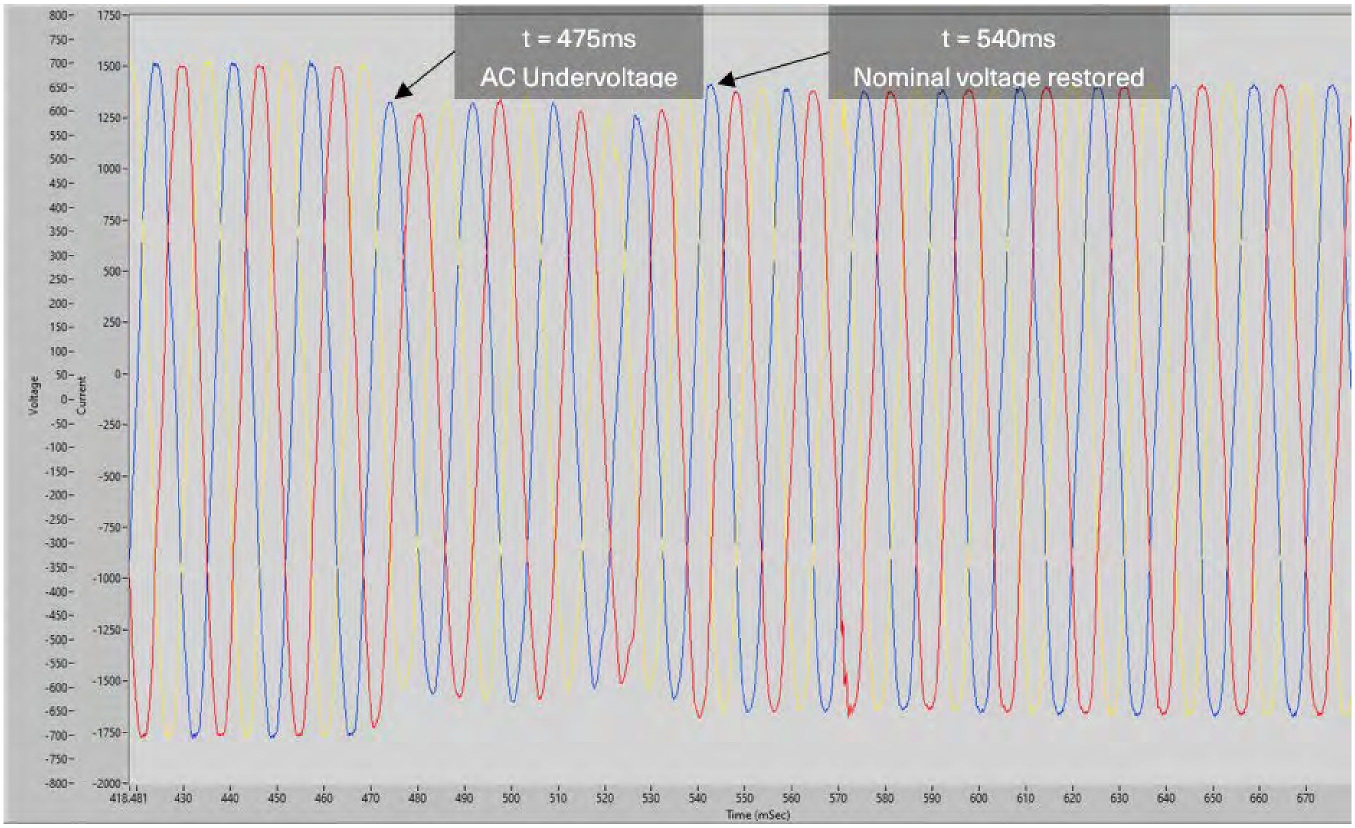

Figure 10– ***AC voltage waveforms***, critical load recovery from voltage sag on utility feed.

Trace Definitions: Light Blue = Ia, Orange = Ib, Dark Blue = Ic, Red = Vab

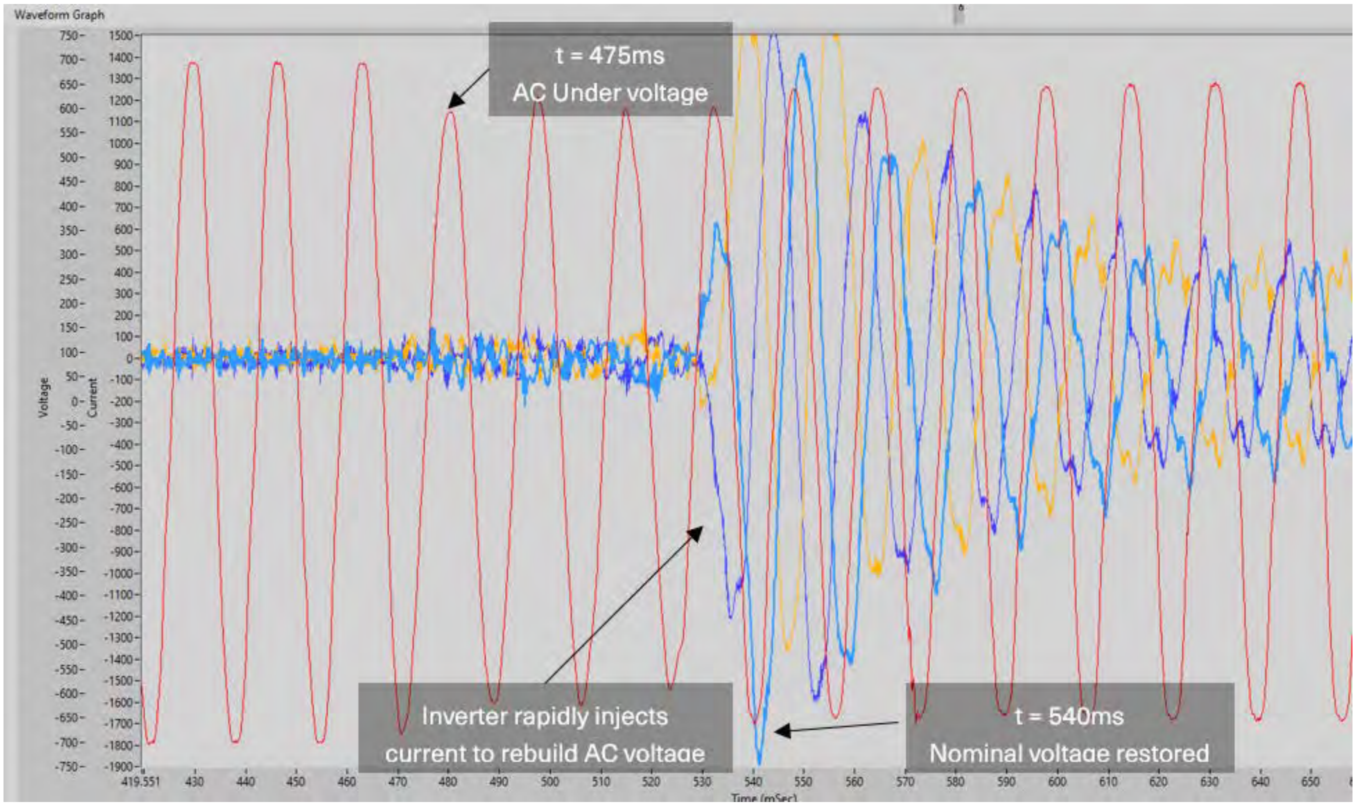

Figure 11 – ***AC current waveforms***, critical load recovery from voltage sag on utility feed.

Total transfer time in this instance is **~0.065 second**, from initial undervoltage to restoration of nominal voltage. Again, the critical load was successfully isolated from utility voltage sag and operations continued unabated.

Dynamic Transfer Timing (UF to PQ) - Return to Grid-Tied

As previously described, upon return of the grid to valid voltage/frequency bounds, the inverter will begin a 'Grid OK' countdown timer. Upon satisfaction of the 'Grid OK' timer, the inverter will synchronize the microgrid to the utility by matching the grid's voltage magnitude and voltage phase angle.

Once synchronized, the inverter will command the grid disconnect to close. The result is a restoration of utility service to the critical load with no interruption of service. This transition is transparent to the load. The inverter then switches back to PQ mode to resume grid-tied operations.

Trace Definitions: Red = Vab, Yellow = Vbc, Blue = Vca

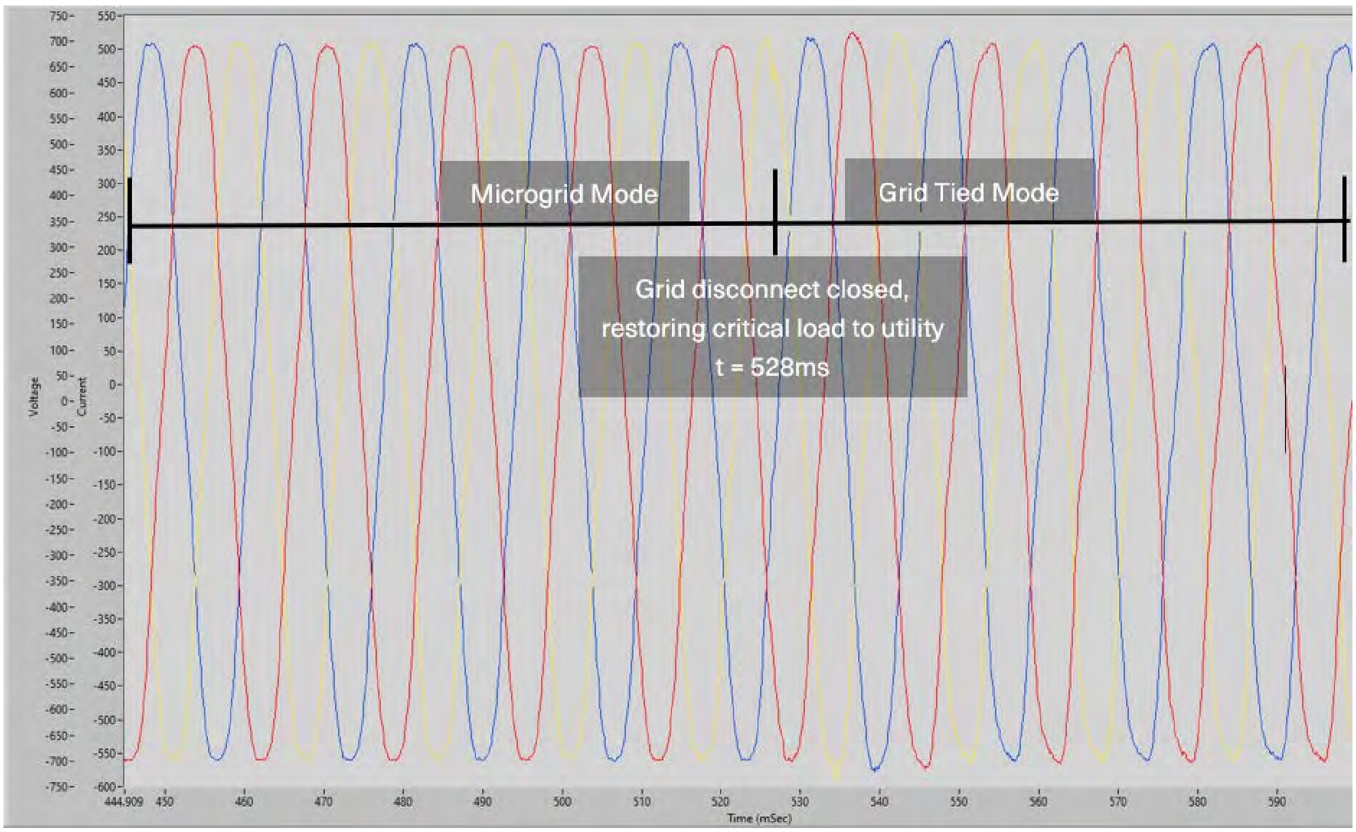

Figure 12 – AC voltage waveforms, critical load reconnection to utility feed.

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