NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Incident Review

Considering Simultaneous Voltage-Sensitive Load Reductions

Primary Takeaways

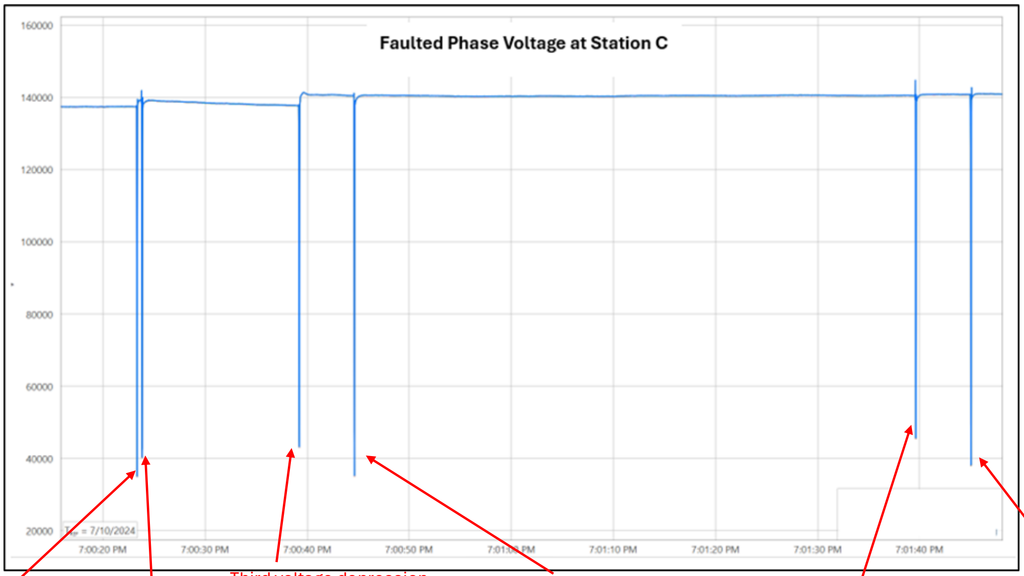
Operators and planners of the Bulk Electric System (BES) should be aware of the risks and challenges associated with voltage-sensitive large loads that are rapidly being connected to the power system. Specifically, when considering data centers and cryptocurrency mining facilities, entities should be aware of the potential for large amounts of voltage-sensitive load loss during normally cleared faults on the BES. Voltage-sensitive data center-type loads have increased on the system and are predicted to continue growing rapidly. The 2024 NERC *Long-Term Reliability Assessment* (LTRA) documents and discusses this potential growth of data center-type loads. This vignette highlights this load-loss potential based on analysis of a recent event in the Eastern Interconnection and offers some considerations for BES operators, planners, and regulators concerning identifying and mitigating the potential reliability effects and risks presented by these large voltage-sensitive load losses for future operations.

Summary of Incident

A 230 kV transmission line fault led to customer-initiated simultaneous loss of approximately 1,500 MW of voltage-sensitive load that was not anticipated by the BES operators. The electric grid has not historically experienced simultaneous load losses of this magnitude in response to a fault on the system, which has historically been planned for large generation losses but not for such significant simultaneous load losses. Simultaneous large load losses have two effects on the electric system: First, frequency rises on the system as a result of the imbalance between load and generation; second, voltage rises rapidly because less power is flowing through the system. In this incident, the frequency did not rise to a level high enough to cause concern. The voltage also did not rise to levels that posed a reliability risk, but operators did have to take action to reduce the voltage to within normal operating levels. However, as the potential for this type of load loss increases, the risk for frequency and voltage issues also increases. Operators and planners should be aware of this reliability risk and ensure that these load losses do not reach intolerable levels.

Incident Details

At approximately 7:00 p.m. Eastern on July 10, 2024, a lightning arrestor failed on a 230 kV transmission line in the Eastern Interconnection, resulting in a permanent fault that eventually “locked out” the transmission line. The auto-reclosing control on the transmission line was configured for three auto-reclose attempts staggered at each end of the line. This configuration resulted in 6 successive system faults in an 82-second period. The protection system detected these faults and cleared them properly. The shortest fault duration was the initial fault at 42 milliseconds, and the longest fault duration was 66 milliseconds. The voltage magnitudes during the fault ranged from .25 to .40 per unit in the load-loss area.



First voltage depression - Initial Fault – arrestor failure

Second voltage depression – 1st automatic reclose attempt – instantaneous at both ends of line

Third voltage depression – 2nd automatic reclose attempt on terminal A of line – 15 second delay

Fourth voltage depression – 2nd automatic reclose attempt on terminal B of line – 20 second delay

Fifth voltage depression – 3rd automatic reclose attempt on terminal A of line – 75 second delay

Sixth voltage depression – 2nd automatic reclose attempt on terminal B of line – 80 second delay

Figure 1: Faulted Phase Voltage

Table 1: Voltage Depression Times and Durations

		Voltage Depression Time (hh:mm:ss.msec)	Voltage Depression Duration (milliseconds)
Voltage Depression 1	Initial Fault (arrestor failure)	19:00:23.351	42
Voltage Depression 2	Instantaneous and simultaneous automatic reclose at both terminals	19:00:23.883	66
Voltage Depression 3	2nd Automatic reclose at terminal A	19:00:39.211	58
Voltage Depression 4	2nd automatic reclose at terminal B	19:00:44.630	50
Voltage Depression 5	3rd automatic reclose at terminal A	19:01:39.600	66
Voltage Depression 6	3rd automatic reclose at terminal B	19:01:45.016	59

Coincident with this six-fault disturbance, the same local area saw an approximate 1,500 MW of load reduction. None of this load was disconnected from the system by utility equipment; rather, the load was disconnected on the customer side by customer protection and controls. It was determined that the 1,500

MW of load reduction was exclusively data center-type load. The area where the disturbance occurred has a high concentration of data center loads.

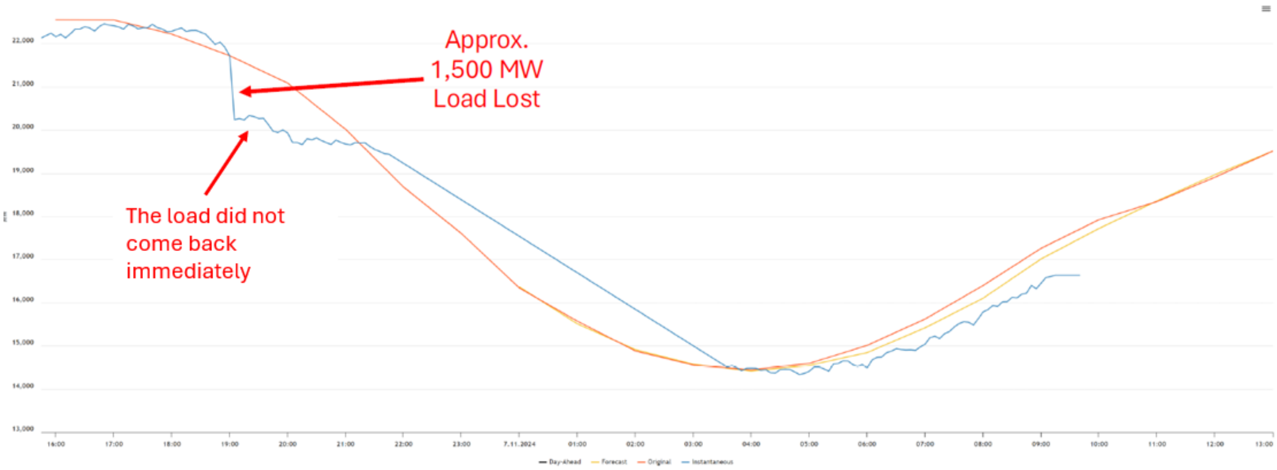


Figure 2: System Load Chart

Frequency and voltage rose due to the load loss. Frequency rose to a high of 60.047 Hz and settled back to 60.0 Hz in approximately 4 minutes. At the highest level, voltage rose to 1.07 per unit. Operators removed shunt capacitor banks in the local area to return voltages to normal operating values.

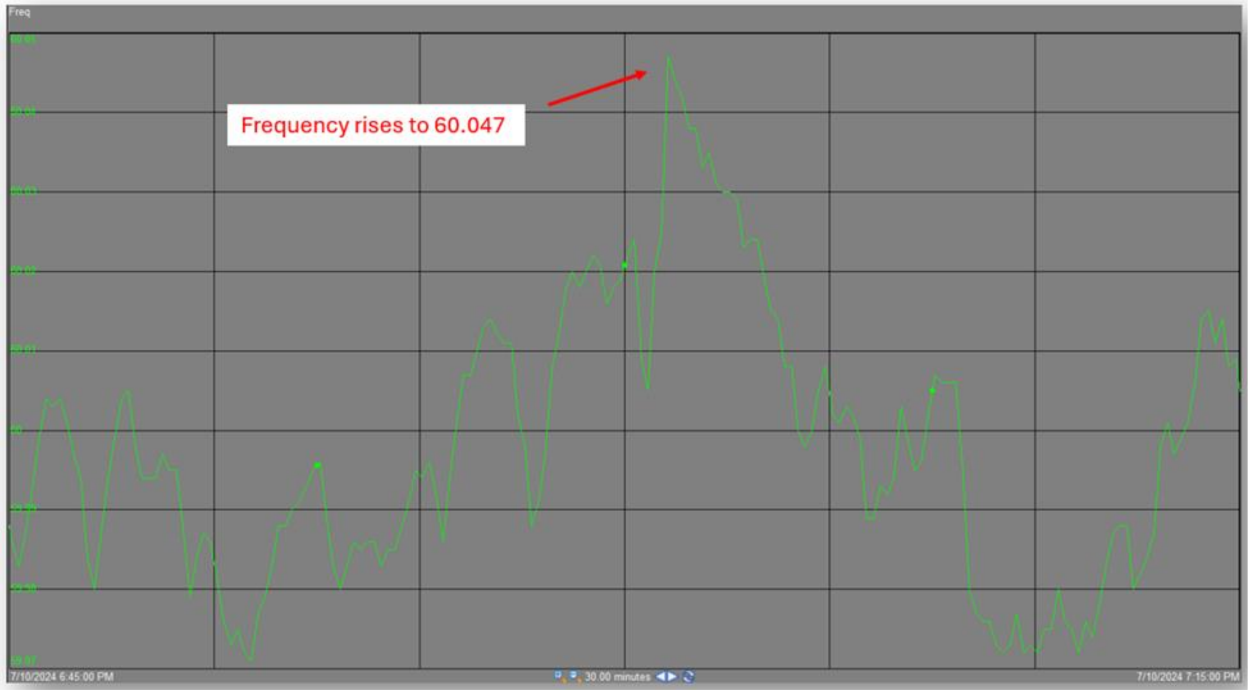


Figure 3: Frequency at Time of Load Loss

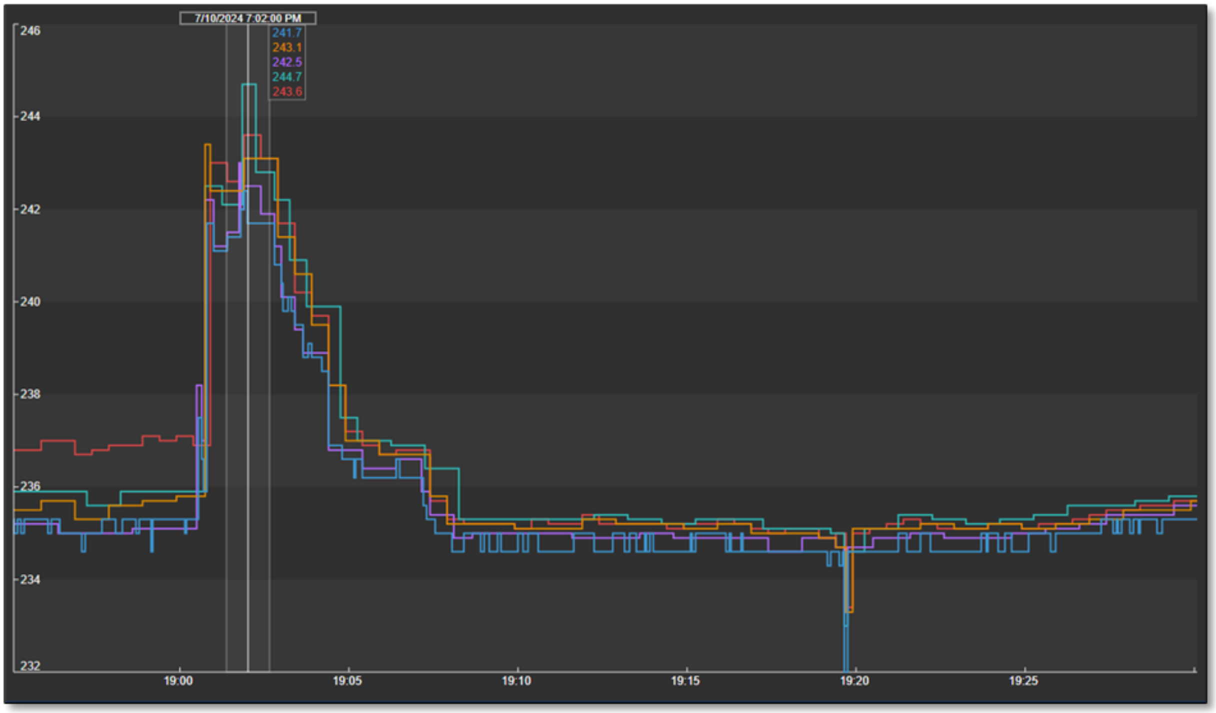


Figure 4: 230 kV Voltages

Load Details

Discussions were held with data center owners to understand the specific cause of their load reductions. It was determined that the data centers transferred their loads to their backup power systems in response to the disturbance. Data center loads are sensitive to voltage disturbances. The data center protections and controls are designed to avoid equipment outages for voltage disturbances. In addition to the computer equipment at these facilities, cooling equipment is also critical to the operation of the data center and sensitive to voltage disturbances. To ride through voltage disturbances on the electric grid, data centers employ uninterruptible power supply (UPS) systems that will instantaneously take over providing power to the data center equipment when a grid disturbance occurs. The differing types and designs of these UPS systems cause differences in the characteristics of the data center responses to a voltage disturbance. A centralized design uses UPS systems at the load-center level that are typically in the range of 2–5 MWs. The UPS uses power electronics to switch the load to a battery bank connected to the UPS. These battery banks are not designed to supply the load for long periods of time but rather to power the load for the short time periods of disturbances or—in the case of a complete electric grid outage—long enough to start a backup generator that will then provide power to the UPS. The decentralized UPS design uses many smaller UPSs at the rack level. These rack-mounted UPSs are typically in the range of 3–4 kW. The decentralized UPS systems operate similarly to the centralized UPS systems, just on a smaller scale. Another type of UPS is a dynamic/diesel rotary uninterruptible power supply (DRUPS). These systems use a flywheel to provide uninterruptible power and a clutch system to quickly start and connect a diesel engine upon a disturbance on the electric grid.

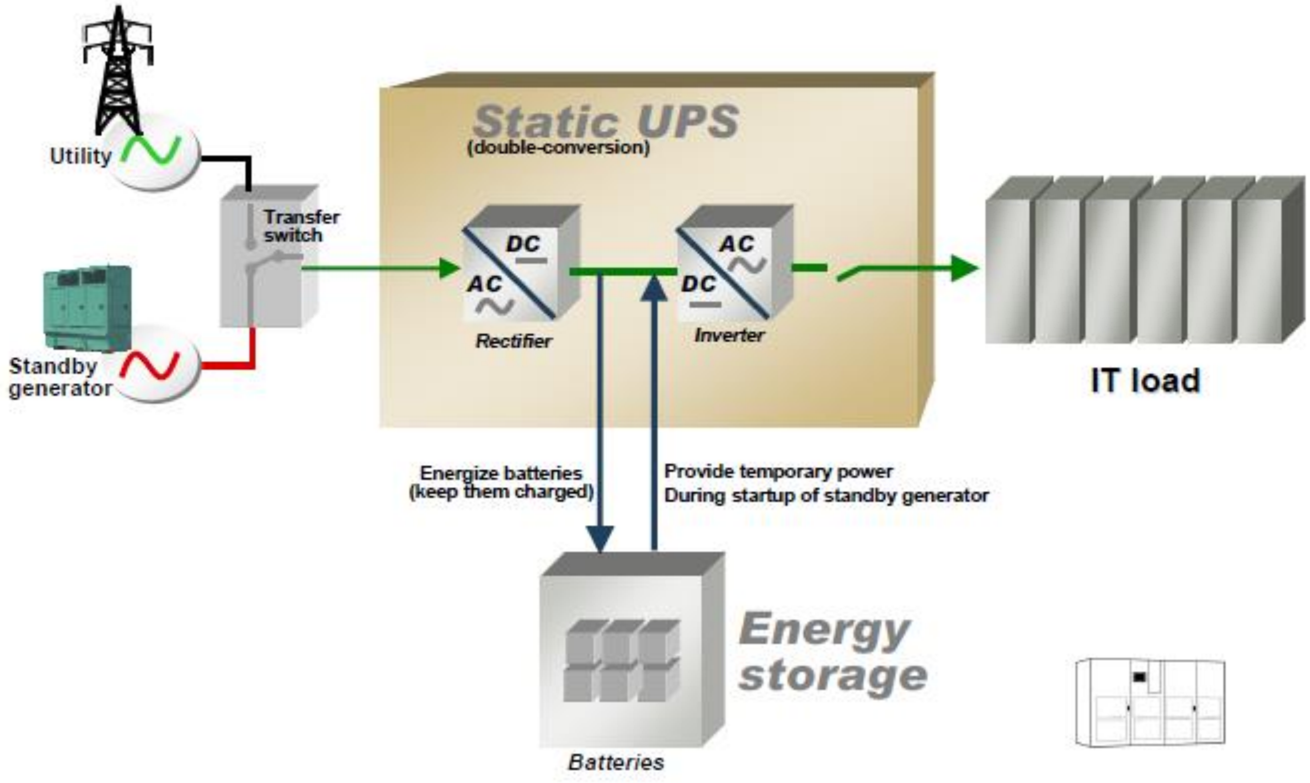


Figure 5: Static Centralized UPS
[Source: Schneider Electric White Paper 92]

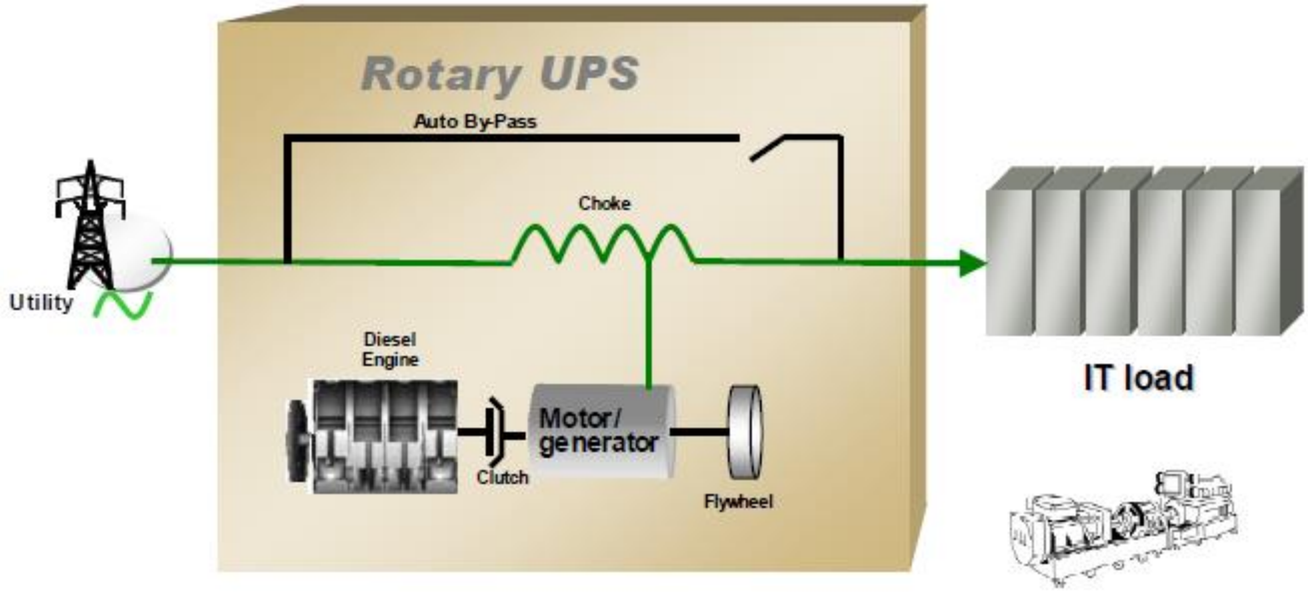


Figure 6: DRUPS
[Source: Schneider Electric White Paper 92]

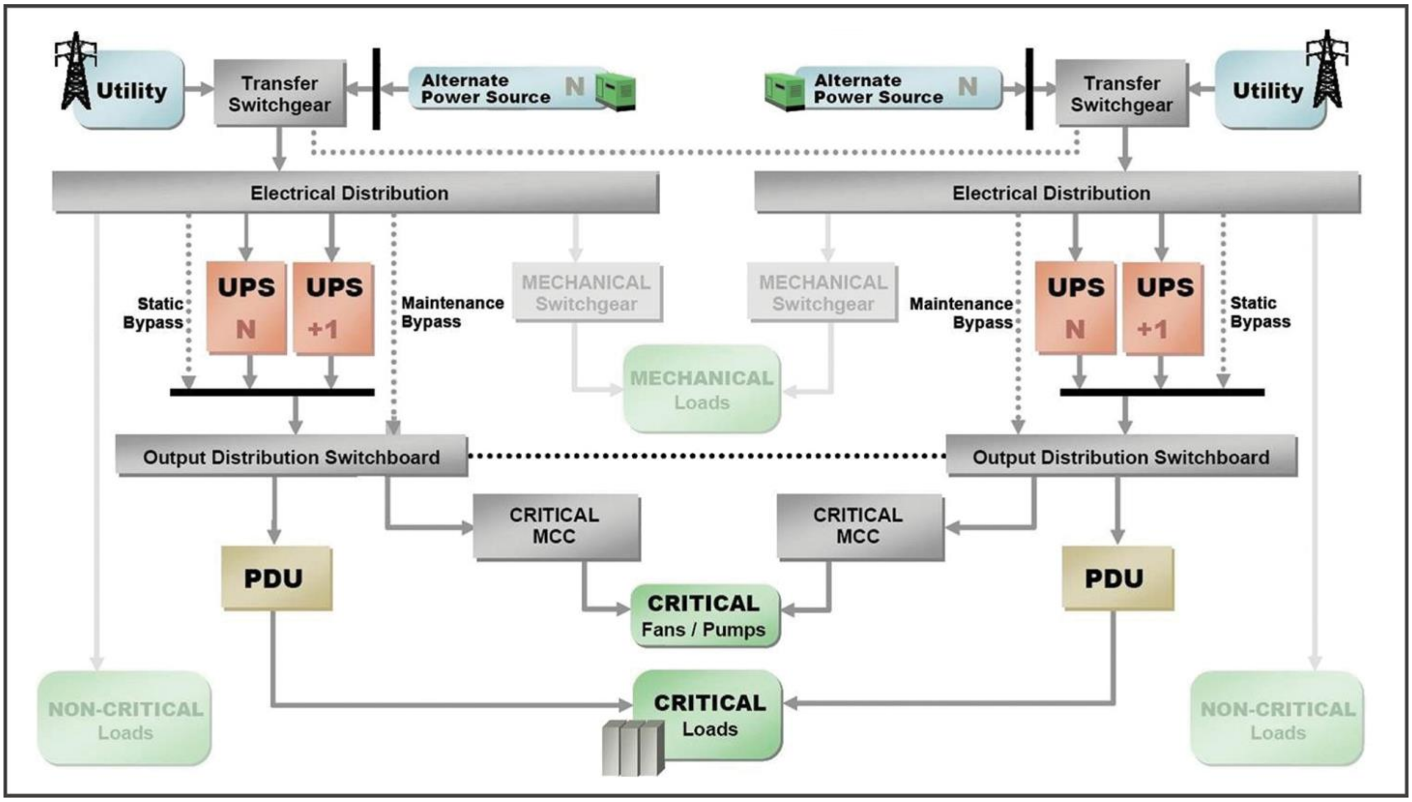


Figure 7: Typical Centralized UPS Power Distribution
[Source: Uptime Institute Journal]

The load characteristics of these types of UPS systems differ in response to a transient disturbance on the electric grid. For the static centralized and decentralized UPS systems that utilize batteries, the load will be taken over by the battery when the transient voltage disturbance occurs. Since it is a transient disturbance, such as a temporary fault on the electric grid, the grid voltage will typically return to normal in milliseconds. Once the grid voltage returns to normal, the load will then be transferred back to the grid. A typical load characteristic for these types of static UPS systems, as seen by the grid, is shown in **Figure 8**. Upon detecting the transient voltage disturbance, the DRUPS system will immediately transfer the load to the flywheel/ac generator and start the engine that will act as the prime mover for the generator before the flywheel exhausts its kinetic energy. This system will not quickly transfer the load back to the grid after the transient disturbance has cleared and the grid voltage returns to normal. Typically, transferring the load back to the grid from the DRUPS system must be done manually. A typical load characteristic for a DRUPS system, as seen by the grid, is shown in **Figure 9**. As can be seen in these figures, the typical static UPS system load characteristic, as seen by the grid, is a short-duration loss of load that returns quickly after the transient disturbance clears. The typical DRUPS system load characteristic, as seen by the grid, is a loss of load that does not return quickly after the transient disturbance clears.

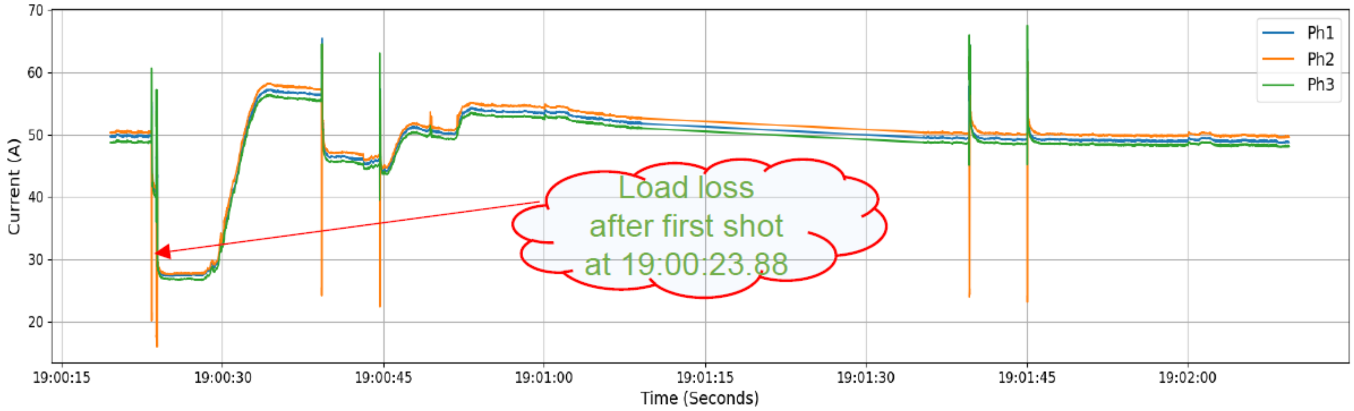


Figure 8: Static UPS Load Characteristic

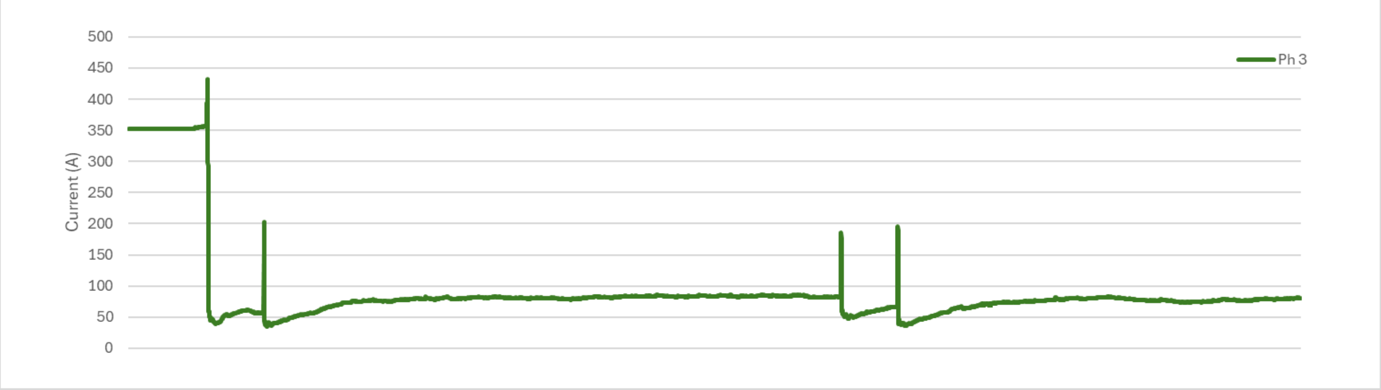


Figure 9: DRUPS Load Characteristic

Discussions with the data center owners also identified another protection/control scheme that impacts the response of data center load to voltage disturbances on the grid. The scheme detects and counts voltage disturbances on the grid. If a certain number of voltage disturbances are seen within a certain time, the data center will transfer its load to the backup system, and it will remain there until it is manually reconnected to the grid. The typical number of voltage disturbances that trigger this scheme is three, and a typical time is one minute. As such, three voltage disturbances within one minute will result in data centers using this protection/control scheme transferring their load off the grid and staying off until they manually transfer back. This scheme can be deployed on both centralized and decentralized UPS designs. A load characteristic for this type of data center control scheme can be seen in Figure 10.

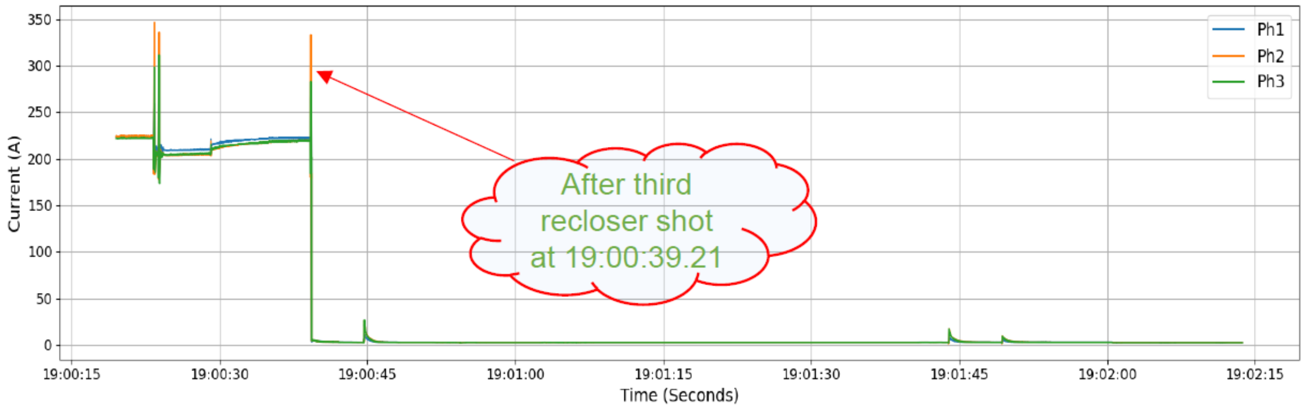


Figure 10: Voltage Disturbance Counting Scheme Load Characteristic

While these three load characteristics were predominant in this event, many load characteristic variations exist. These characteristics are determined by the numerous vendor-supplied equipment controls within the data center, including the vendor-specific UPS controls. Additionally, controls under the purview of data center owner/operators, such as a certain number of disturbances within a certain period of time, also determine the characteristic response to system disturbances.

Most of the sustained load reduction occurred simultaneously with the third voltage depression, which coincided with the third automatic reclosing attempt. At that time, approximately 1,260 MW of load dropped off the electric grid and did not return for hours. Most of the load loss in this event can be attributed to the interaction between the automatic reclosing sequence on the faulted transmission line and the data center’s protection/control scheme that counts the number of voltage disturbances within a specified period of time.

While this incident did not present any significant issues with the reconnection of the large loads, the potential exists for issues in future incidents if the load is not reconnected in a controlled manner. Significant amounts of load being reconnected to the system present challenges to Balancing Authorities (BA) and Transmission Operators (TOP). Ramp rates for load connection are just as critical to system operations as generation ramping. Voltage management and maintaining balance between load and generation are considerations that need to be given for load reconnection ramp rates.

This incident has highlighted potential reliability risks to the BES with respect to the voltage ride-through characteristics of large data center loads. Similar incidents have occurred in other Interconnections with cryptocurrency mining loads as well as oil/gas loads. While these loads are different than the data center loads in this incident, they present the same challenges to the operators and planners of the BES. Understanding the changing dynamic nature of load is critical to the future operation of the BES.

Future Considerations

While this disturbance did not cause significant operating issues with the grid at this location and at this time, as data center loads continue to grow rapidly, the risk could quickly increase. Actions that TOPs and Transmission Planners (TP) should start taking to avoid significant issues in the future are listed below:

- Require dynamic response models of large loads in their facility interconnection requirements

- Perform studies to determine the potential magnitude of load loss for system disturbances (faults)
  - Study the impact that these large load losses would have on the system
- Take into consideration the potential for voltage-sensitive load loss when configuring automatic reclosing schemes
- Actively monitor to detect load losses coincident with system faults
- TOPs: Ensure that operating agreements with large loads include ramp rates when connecting/reconnecting large loads to the system
- Critical questions that must be resolved:
  - Should large loads be a NERC registered entity?
  - Should NERC Reliability Standard modifications be developed for large load interconnection requirements?
  - What studies should TOPs perform to "consider" the impacts of large load operation?
  - What is the definition of a large load?

Transmission Owners (TO), TOPs, TPs, and large-load owners will have to work collaboratively to identify and mitigate reliability risks posed by large load losses during system faults. The NERC Large Load Task Force (LLTF) is one group where this type of collaboration can take place.

For more information, please contact:
NERC – Event Analysis

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