QUANTITATIVE EFFICIENCY ANALYSIS OF POWER DISTRIBUTION CONFIGURATIONS FOR DATA CENTERS

Version 1.0 Release Date: 1 December 2008

EXECUTIVE SUMMARY

This analysis builds on the previously released "Qualitative Analysis of Power Distribution Configurations For Data Centers." It takes a quantitative look at one aspect of the previous paper -- efficiency.

This paper studies the end-to-end efficiency of eight simplified, non-redundant data center power distribution configurations. The data shows that a data center with optimized implementations of all of the topologies achieve approximately 25% higher efficiency than a typical data center of 10 years ago, delivering between 85% and 90% end-to-end efficiency over a wide load range. The highest efficiency AC and DC configurations are within 1% to 2% of each other and are only 2% to 3% better than double conversion 480Vac – 208Vac over the majority of the load range. No single configuration provides the highest efficiency at every load.

the green grid™

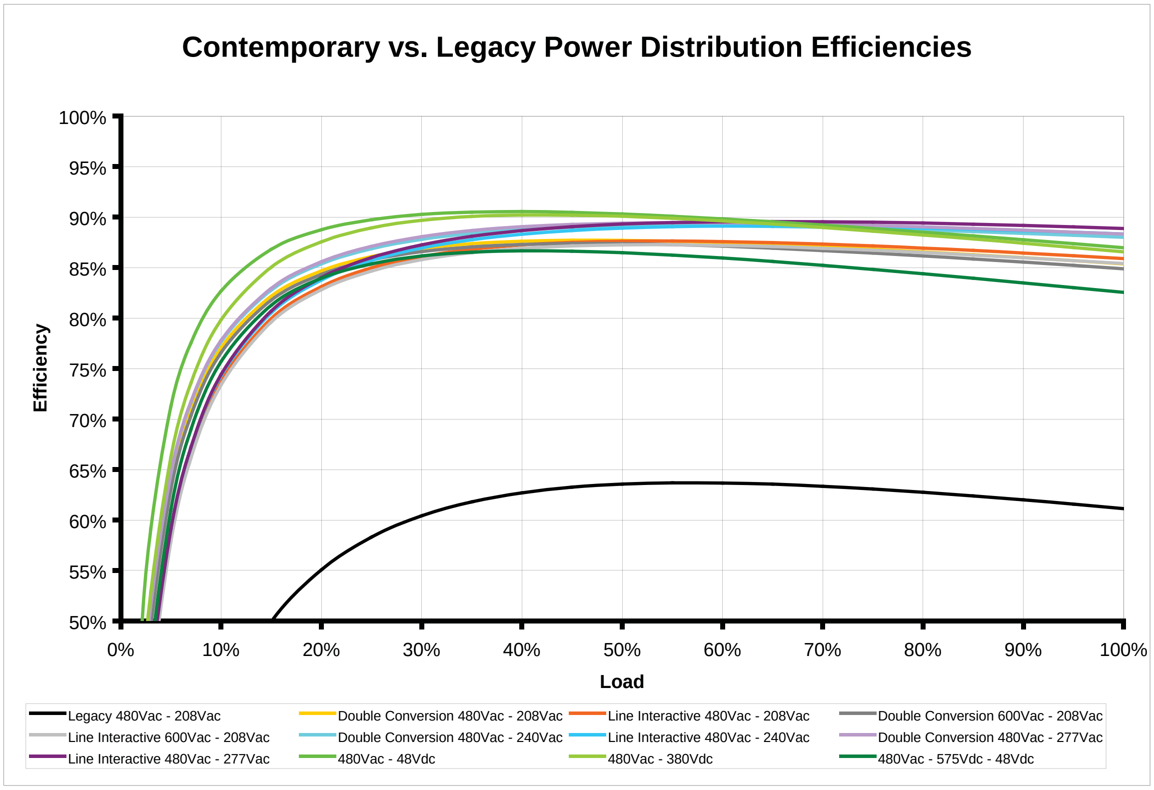

FIGURE 1. END-TO-END EFFICIENCY COMPARISON OF ALL CONFIGURATIONS

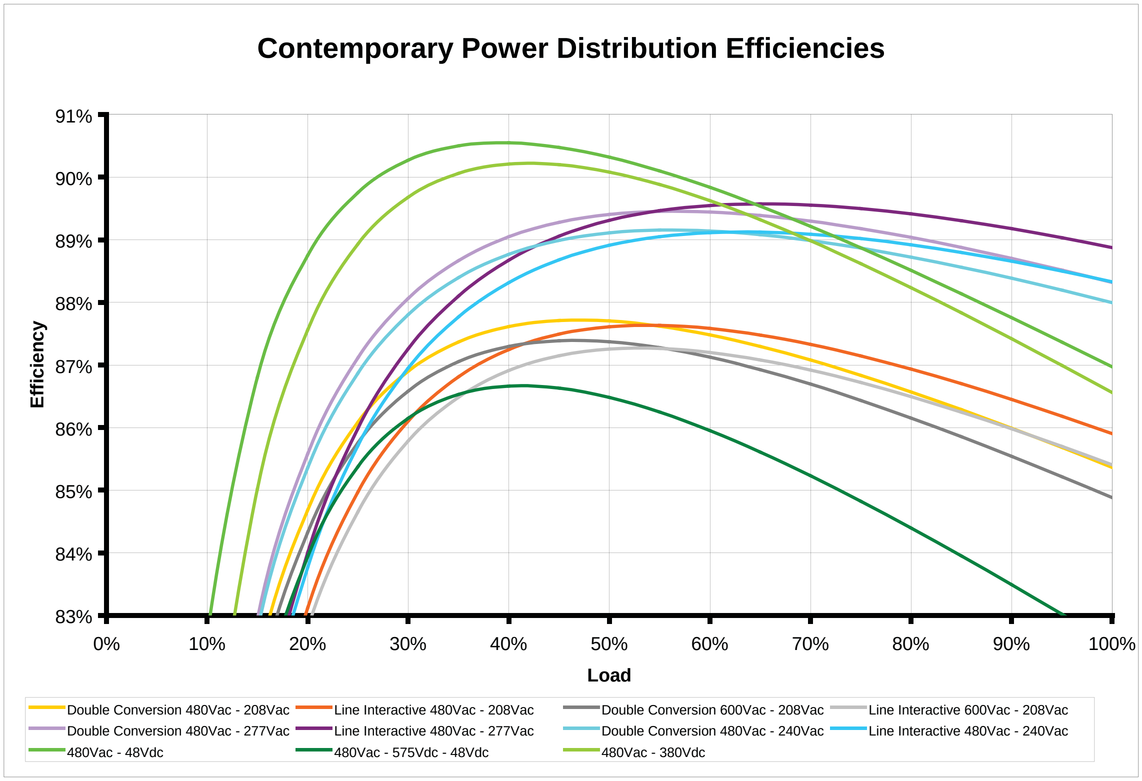

FIGURE 2. END-TO-END EFFICIENCY COMPARISON, EXCLUDING LEGACY 480VAC – 208VAC

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INTRODUCTION AND BACKGROUND

In 2007, The Green Grid (TGG) released a paper entitled, "Qualitative Analysis of Power Distribution Configurations."[1] The paper examined seven possible data center power distribution configurations by looking at advantages and disadvantages of each in the areas of commonality of deployment, efficiency, reliability, equipment availability, and standardization/acceptance.

One of the most debated topics when discussing different power distribution configurations is efficiency. This paper provides an in-depth efficiency analysis of minimalist, non-redundant, highly optimized implementations of the same power distribution configurations as the qualitative analysis. The naming convention below incorporates the first voltage as the data center input voltage and the second voltage as the power supply unit (PSU) input voltage. The exception is configuration 6, which also includes the intermediate distribution voltage to distinguish it from configuration 5. The configurations included in this paper are:

1. 480Vac – 208Vac
2. 600Vac – 208Vac
3. 480Vac – 277Vac
4. 480Vac – 240Vac
5. 480Vac – 48Vdc
6. 480Vac – 575Vdc – 48Vdc
7. 480Vac – 380Vdc

When choosing a power distribution method for a data center, it is important to recognize that there are many other factors aside from efficiency that play a key role in the configuration choice. They are beyond the scope of this work. For example, the paper does not take into account reliability, acceptance, cost of ownership, or any other topic discussed in the aforementioned qualitative analysis. System designs that factor in considerations for these items will have further impact on the end to end efficiency of the power distribution. Proper system design would include an evaluation of those related issues within the context of the target needs of the data center in question.

The following terms are abbreviated in this document:

- Alternating current is abbreviated "AC"
- Direct current is abbreviated "DC"
- Volts of alternating current is abbreviated "Vac"
- Volts of direct current is abbreviated "Vdc"
- Galvanic isolation is abbreviated "Iso"

Please note that from a safety standpoint, all voltages below 600Vac or 600Vdc are categorized as low voltage per the National Electric Code.

The following is a brief description of the components and subcomponents that are utilized in the various configurations:

MAIN COMPONENTS:

UPS – The uninterruptible power supply (UPS) converts unconditioned power to provide conditioned power to critical loads. It contains an energy storage system, such as batteries, that can supply power to the load when utility power is unavailable. This paper's analysis includes double conversion AC UPSs, line interactive AC UPSs, and DC UPSs. Note that although a data center commonly has multiple UPSs, they are modeled as a single block. DC UPSs also are modeled as a single block, even though they may actually consist of multiple rectifier modules and separate batteries. Where appropriate, isolation is indicated in the block diagrams. Voltage-converting AC UPSs may incorporate an autotransformer in their bypass path. For more detail on UPS types, see IEC 62040-3.[2]

PDU – The main function of a power distribution unit (PDU) is to house circuit breakers that are used to create multiple branch circuits from a single feeder circuit. A secondary function of some PDUs is to convert voltage. The AC voltage–converting PDUs contain either an isolation transformer or an autotransformer to step the AC distribution voltage down to the power supply input voltage. The DC voltage–converting PDUs contain DC/DC converters. A data center typically has multiple PDUs. Note that for simplicity, multiple PDUs are modeled as a single block. Where appropriate, isolation is indicated in the block diagrams.

PSU – The power supply unit (PSU) converts an input voltage to a regulated 12Vdc output voltage. The single PSU block shown in each configuration diagram represents the aggregation of all server power supplies. All PSUs in this analysis provide isolation. For the purpose of this analysis, power supplies must be designed to power a single server chassis as part of a redundant configuration. They must have an EMI filter, input reverse current protection, sufficient capacitance to provide adequate hold up time and output OR-ing circuitry. Additionally, AC power supplies must have active power factor correction. Note that in keeping with standard industry practice, PSU internal fan power is excluded from the efficiency measurements. [3]

SUBCOMPONENTS:

Rectifier (Rec) – An electronic device that converts alternating current to direct current. In this analysis, all rectifiers are power factor corrected.

Inverter (Inv) – An electronic device that converts direct current to alternating current.

Battery (Batt) – An energy storage device that stores chemical energy and makes it available as DC electrical power.

Static Disconnect Switch (SDS) – An electronic device that quickly disconnects the inverter from the utility power input.

Isolation transformer (Iso Xfmr) – An electromagnetic device with multiple windings per phase that converts single AC voltage to another AC voltage and provides galvanic isolation.

Autotransformer (Auto Xfmr) – An electromagnetic device with a single winding per phase that converts one AC voltage to a different AC voltage and does not provide isolation. Autotransformers are generally more efficient than similarly rated isolation transformers.

DC/DC converter (DC/DC) – An electronic device that converts a single DC voltage to another DC voltage and provides galvanic isolation.

STUDY METHODOLOGY

For this study, The Green Grid collected efficiency data as a function of load for multiple versions of each component in every configuration. From the collected data, the most efficient component within each category was identified. From there, the best components of each category were combined to calculate an overall end-to-end (480 or 600Vac in to 12Vdc out) efficiency curve for each configuration.

The Green Grid obtained data from both publicly available and proprietary sources. For data to be eligible for inclusion in the study, it must have been measured, not estimated or calculated. All measurements came from either production units or prototype units of production quality. None of the data was measured by The Green Grid; it was all measured by the component supplier or a third party.

The efficiency data was converted into loss data, which was fit to a second-order curve. The loss curve equation was used to calculate the efficiency equation, which was plotted over the entire load range. To calculate the curve for an entire configuration, the efficiency curves of the appropriate components were multiplied together, along with wiring losses. The end-to-end efficiency curve then was plotted over the entire load range. After comparison to other model types, this efficiency multiplication model was determined to be nearly as accurate as more complex models, particularly for loads above 20%. Therefore, because it was simple to understand and implement, and sufficiently accurate, The Green Grid used the efficiency multiplication model for this paper.

Because component efficiency is constantly improving and new products are continuously entering the market, The Green Grid plans to release a similar web based efficiency model that will allow users to input their own component data and calculate the resultant end-to-end configuration efficiency.

Components were selected in capacities commonly used in large data centers. The size range for components was as follows:

- AC UPSs: 250-400kVA
- DC UPSs:
  - 48Vdc Rectifier: 200kW (2kW x 100 units)
  - 575Vdc Rectifier: 350kW
  - 380Vdc Rectifier: 250kW
- Transformers: 288-300kVA
- DC/DC Converter: 575Vdc – 48Vdc 120kW
- PSUs:
  - AC PSU: 1000W
  - 48Vdc PSU: 350W
  - 380Vdc PSU: 1200W

ASSUMPTIONS

This paper makes the following assumptions:

- The configurations range from the standard building entrance voltage of 480 or 600Vac to the typical server internal distribution level of 12Vdc. Medium voltage versions of all configurations exist, but typical practice is to use 480 or 600Vac UPSs and rectifiers. While there are some server types that distribute a higher voltage, 12Vdc is what is most typical in the industry today.

- Power supplies were included in the analysis because their topology and efficiency is dependent on input voltage and therefore will affect overall configuration efficiency.

- The simplified drawings represent actual data center power distribution configurations. Each configuration includes the minimal components that are required to produce an operable system. Actual data center design will vary, but will be a superset of one of these configurations with added components for redundancy.

- The industry trend in all components and topologies is to minimize isolation stages. As isolation stages are removed, the potential consequences of ground faults increase in magnitude. Each configuration includes the minimum number of isolation stages necessitated by the ground bonding practices of that topology.

- Because all modern servers are power factor corrected, all data is measured at nominal line and with resistive loads . [4]

- While not specifically shown in detail in this paper, systems of larger sizes could be implemented with identical efficiency by using multiple instances or these configurations in parallel.

- Wiring and breaker losses were normalized to typical values across all topologies as follows:
  - o UPS to PDU: 1.5%
  - o PDU to PSU: 0.5%

- The model does not account for redundancy and its potential impact on efficiency.

- All designs assume balanced loads with unity power factors and acceptable harmonic currents when operating in normal modes.

- For this analysis, only power topologies that performed conversions at the room level were considered. Other topologies with conversions at rack level are possible. However they are less common and outside the scope of this paper.

- Overall, the end-to-end efficiencies illustrated by this paper will be difficult to achieve in an actual data center because of the following:
  - o While the actual capacities of the components were different, they all were modeled as though they were of equal capacity.
  - o All the components in a given configuration were assumed to be equally loaded.
  - o There was no underutilized capacity anywhere in the system.

DISTRIBUTION CONFIGURATIONS ANALYSIS

The block diagrams shown in each of the following sections can be used to quickly understand and compare the configurations. Each of the major components in a configuration is shown as a yellow box. The subcomponents with losses are shown as smaller blue boxes within the larger yellow components.

Each configuration has a graph containing its component and end-to-end efficiency curves.
Because there are multiple types of AC UPSs in common use today, with different efficiency characteristics, each AC configuration is shown twice, once with a double conversion UPS and once with a line interactive UPS.

To show the progress that has been made in recent years, both legacy and contemporary implementations of the 480Vac – 208Vac configuration are shown.

Legacy 480Vac – 208Vac Distribution Configuration

The legacy 480Vac – 208Vac power distribution configuration is representative of the de facto standard US data center built in the late 20th century. It is modeled using equipment [5,6,7] typical of the era when the choice of equipment was commonly driven by cost, rather than efficiency.

In this configuration, electricity enters the UPS at 480Vac and exits at the same voltage. The electricity then enters the PDU at 480Vac, is converted by an isolation transformer, and exits at 208Vac. Finally, the electricity enters the PSU at 208Vac and is galvanically isolated and converted to 12Vdc for use by the server.

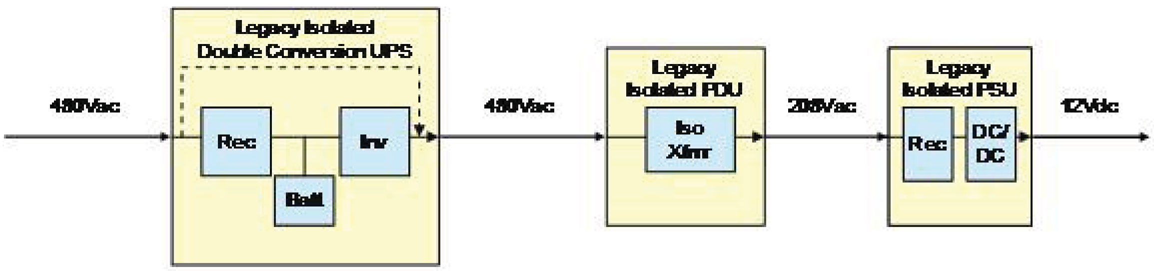

FIGURE 3. LEGACY 480VAC – 208VAC POWER DISTRIBUTION CONFIGURATION

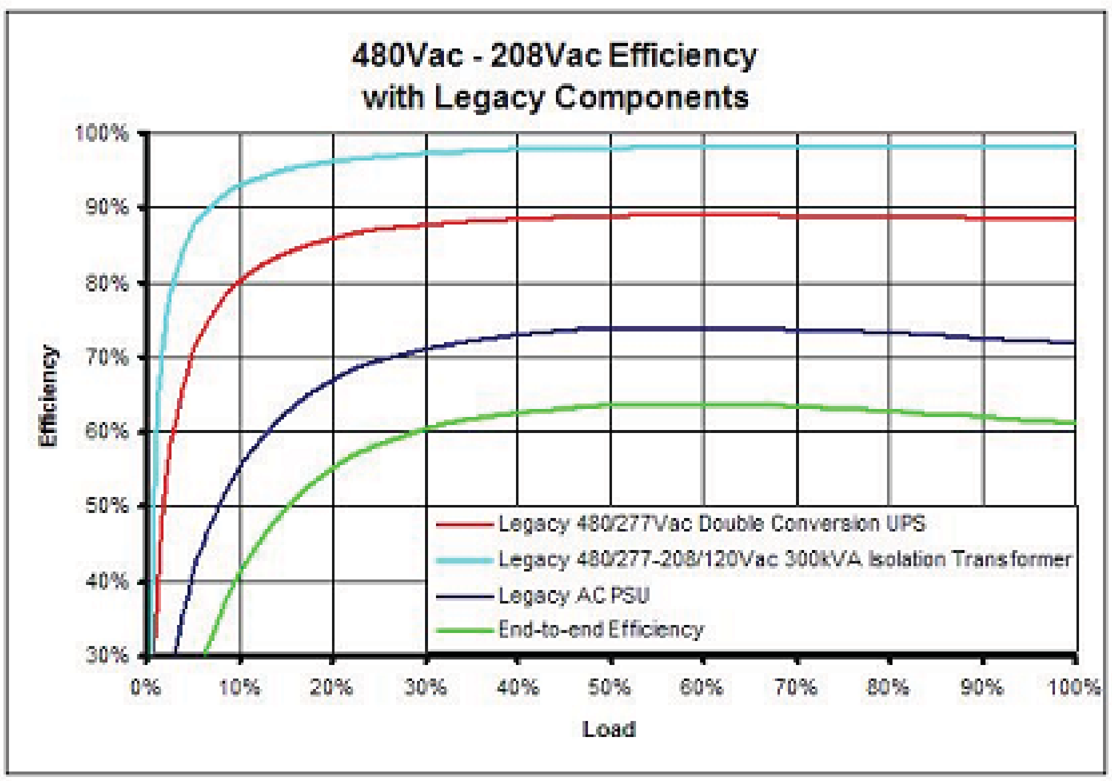

FIGURE 4. COMPONENT AND END-TO-END EFFICIENCY FOR LEGACY 480VAC – 208VAC CONFIGURATION UPS

Distribution Configuration 1. 480Vac – 208Vac

This 480Vac – 208Vac distribution configuration is a contemporary implementation of the popular 480Vac – 208Vac system utilizing the highest-efficiency components currently available.

In this configuration, electricity enters the UPS at 480Vac and exits at the same voltage. The electricity then enters the PDU at 480Vac, is converted by an isolation transformer, and exits at 208Vac. Finally, the electricity enters the PSU at 208Vac and is galvanically isolated and converted to 12Vdc for use by the server. Figure 5 and Figure 6 below show this configuration implemented with different UPS types.

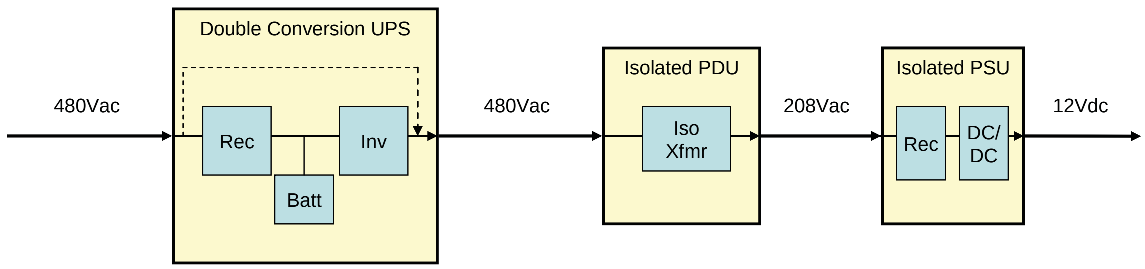

FIGURE 5. 480VAC – 208VAC CONFIGURATION WITH DOUBLE CONVERSION UPS

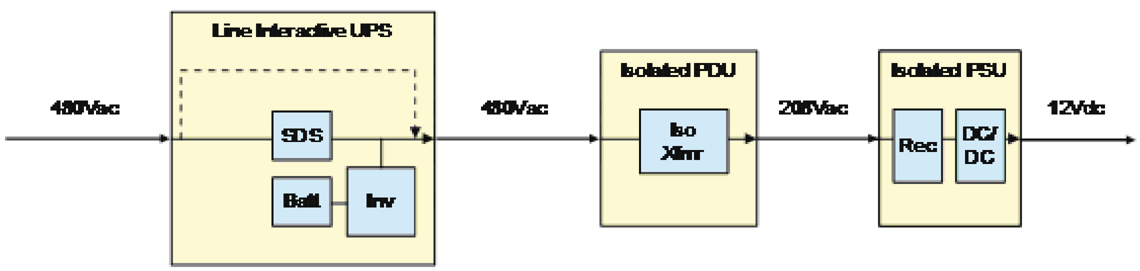

FIGURE 6. 480VAC – 208VAC CONFIGURATION WITH LINE INTERACTIVE UPS

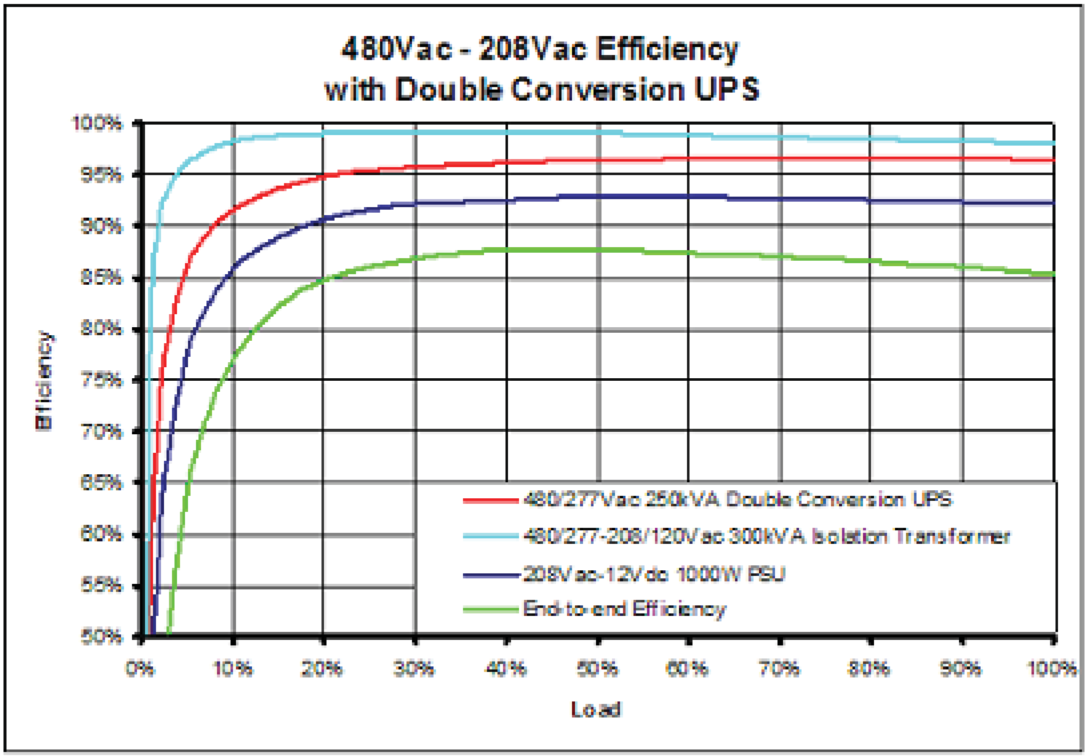

FIGURE 7. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 208VAC WITH DOUBLE CONVERSION UPS

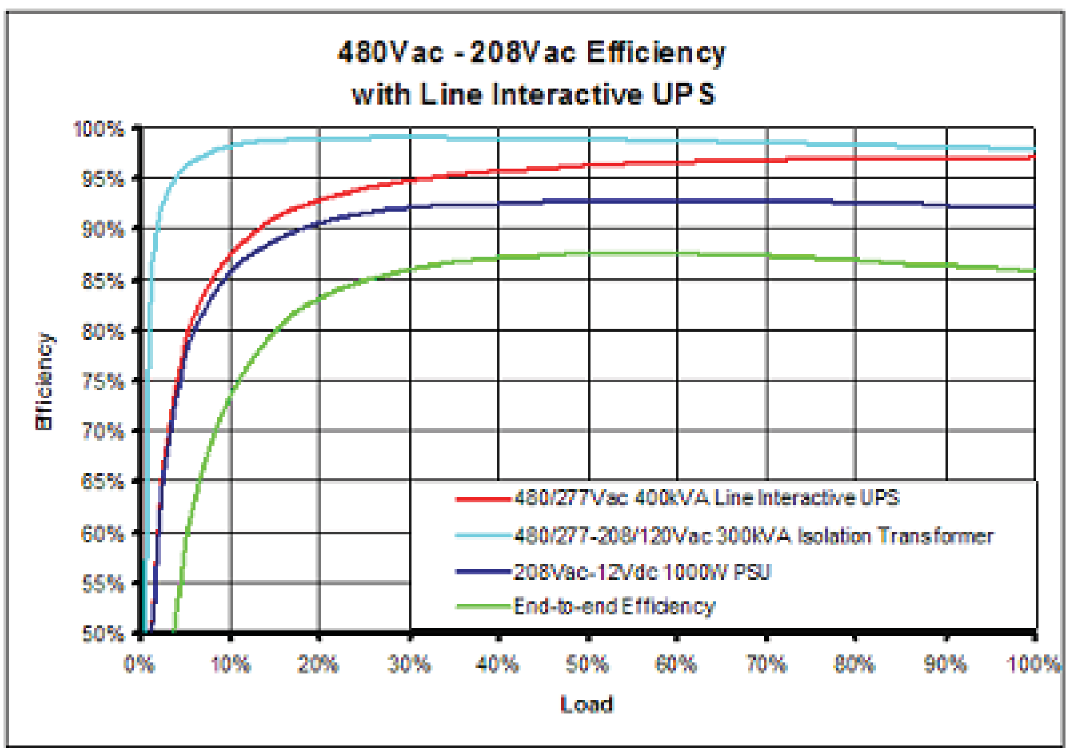

FIGURE 8. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 208VAC WITH LINE INTERACTIVE UPS

Distribution Configuration 2. 600Vac – 208Vac

The 600Vac – 208Vac configuration is identical to the 480Vac – 208Vac except that the input voltage is 600Vac instead of 480Vac. 600Vac – 208Vac is widely used in Canada and it also is used in some large-scale US data centers.

In this configuration, electricity enters the UPS at 600Vac and exits at the same voltage. The electricity then enters the PDU at 600Vac, is converted by an isolation transformer, and exits at 208Vac. Finally, the electricity enters the PSU at 208Vac and is galvanically isolated and converted to 12Vdc for use by the server. Figure 9 and Figure 10 below show the same configuration implemented with different UPS types.

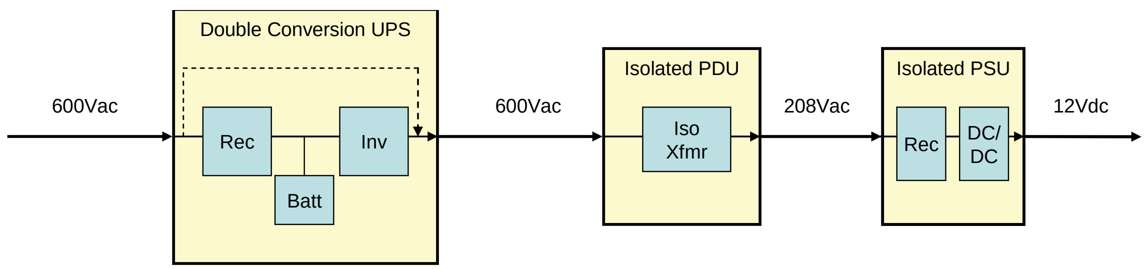

FIGURE 9. 600VAC – 208VAC CONFIGURATION WITH DOUBLE CONVERSION UPS

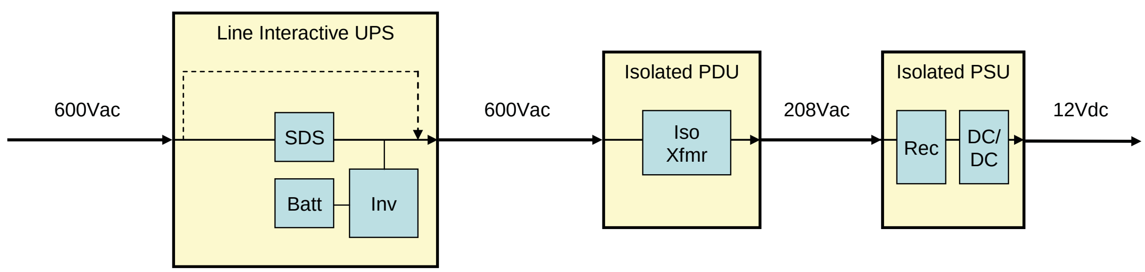

FIGURE 10. 600VAC – 208VAC CONFIGURATION WITH LINE INTERACTIVE UPS

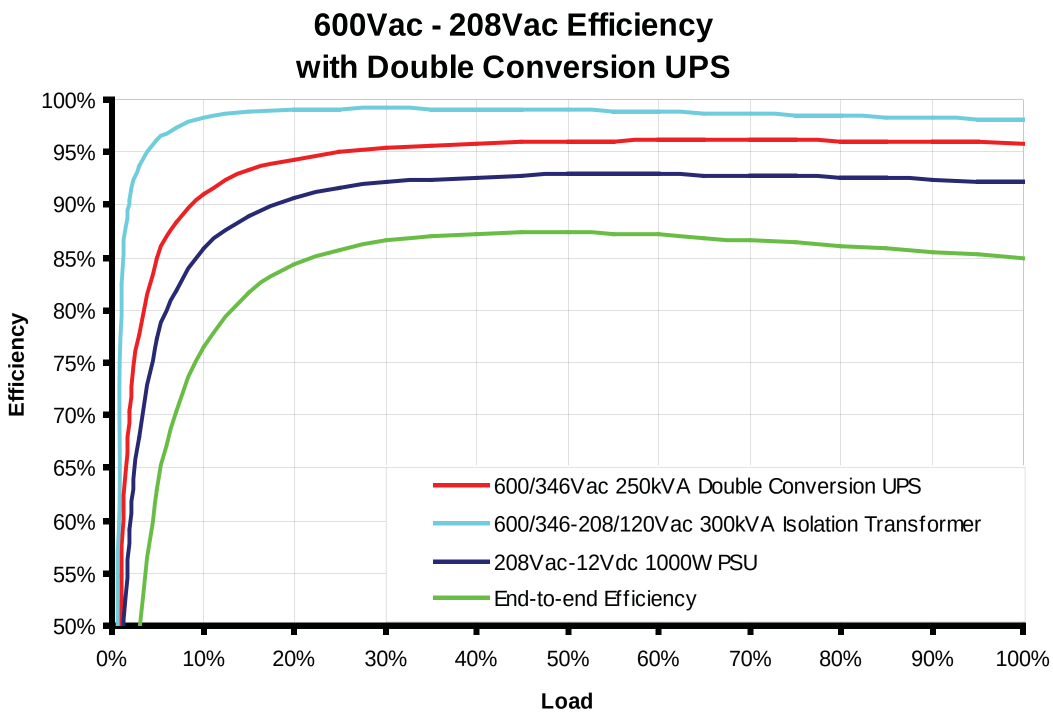

FIGURE 11. COMPONENT AND END-TO-END EFFICIENCY FOR 600VAC – 208VAC WITH DOUBLE CONVERSION UPS

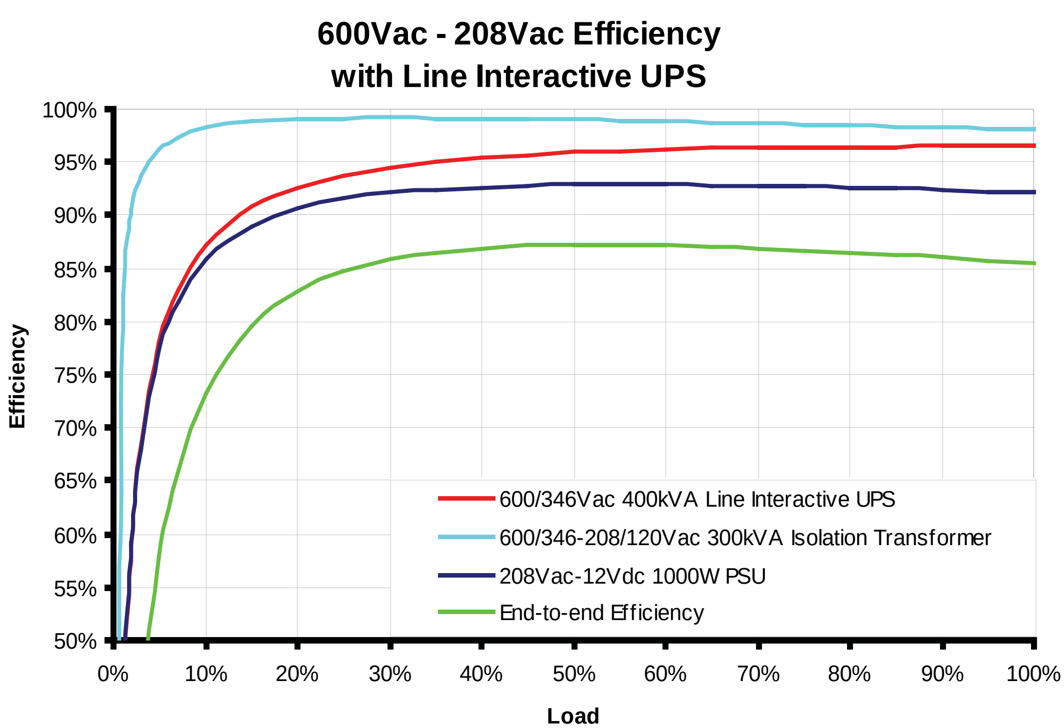

FIGURE 12. COMPONENT AND END-TO-END EFFICIENCY FOR 600VAC – 208VAC WITH LINE INTERACTIVE

Distribution Configuration 3. 480Vac – 277Vac

This configuration is the US equivalent of the 400Vac/230Vac and 415Vac/240Vac distribution methods that are ubiquitous in the rest of the world. These systems distribute electricity in a wye configuration at a consistent voltage throughout the topology and the servers are powered from phase-to-neutral rather than phase-to-phase voltage.

In this configuration, electricity enters the UPS at 480/277Vac and exits at the same voltage. The electricity then enters the PDU at 480/277Vac and exits at the same voltage. Finally, the electricity enters the PSU at 277Vac and is galvanically isolated and converted to 12Vdc for use by the server. Figure 13 and Figure 14 below show the same configuration implemented with different UPS types.

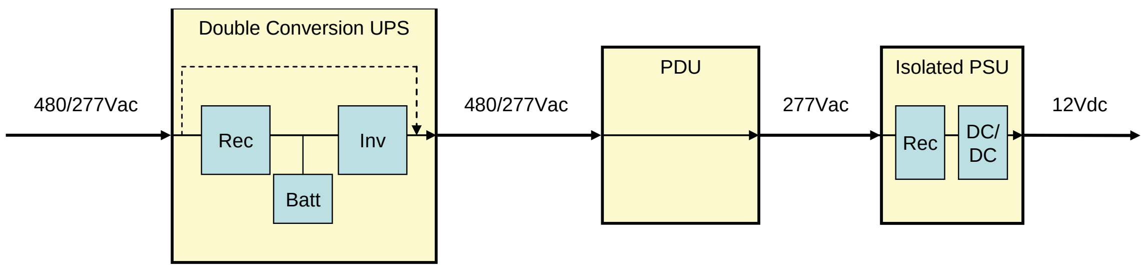

FIGURE 13. 480VAC – 277VAC CONFIGURATION WITH DOUBLE CONVERSION UPS

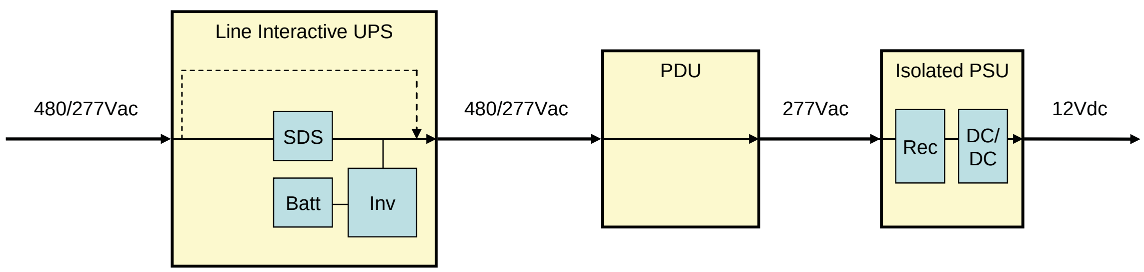

FIGURE 14. 480VAC – 277VAC CONFIGURATION WITH LINE INTERACTIVE UPS

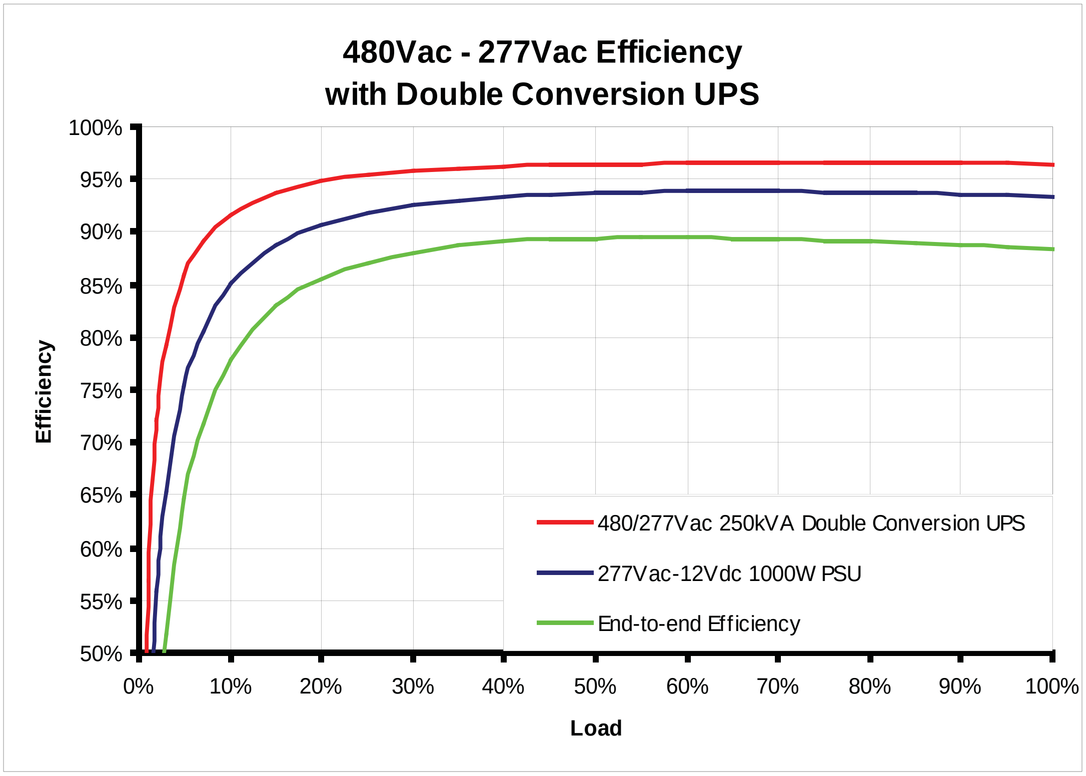

FIGURE 15. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 277VAC WITH DOUBLE CONVERSION UPS

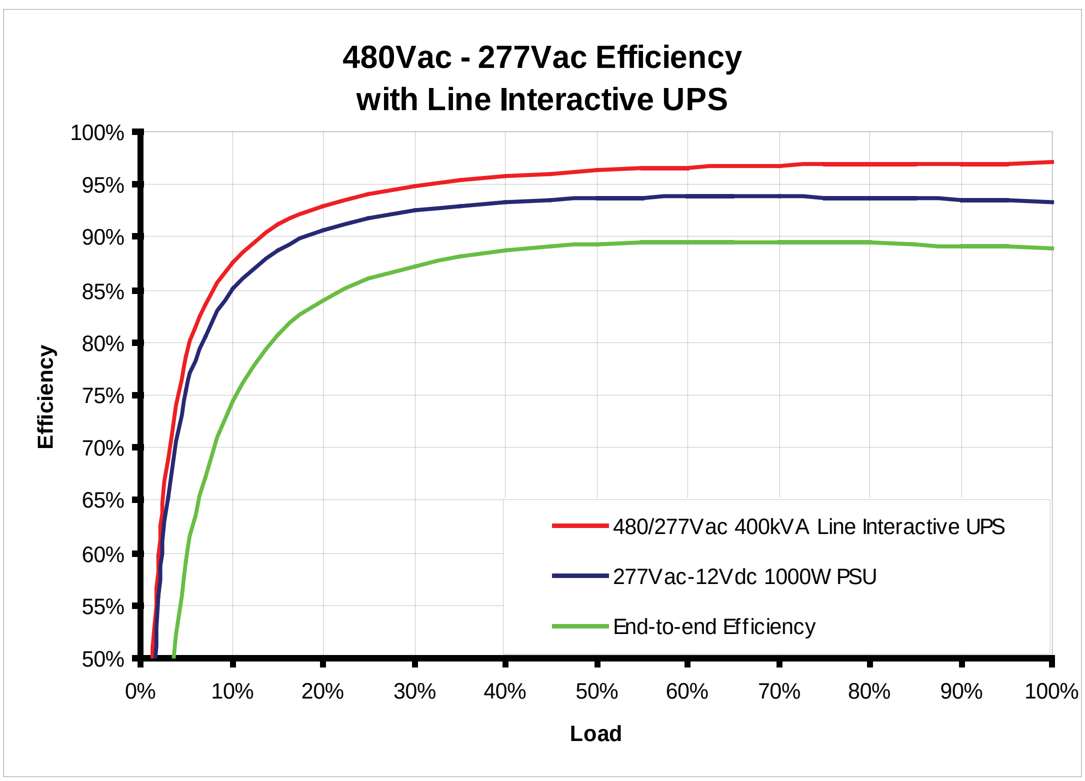

FIGURE 16. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 277VAC WITH LINE INTERACTIVE UPS

Distribution Configuration 4. 480Vac – 240Vac

This configuration brings the 415/240Vac system, ubiquitously deployed outside of the US, to North America. Because US data centers commonly only have 480/277Vac available, a conversion must occur to create the desired 415/240Vac.

Figure 17 illustrates a variant of the configuration where the double conversion UPS converts the voltage. In this configuration, electricity enters the UPS at 480/277Vac and exits at 415/240Vac. The electricity then enters the PDU at 415/240Vac and exits at the same voltage. Finally, the electricity enters the PSU at 240Vac and is galvanically isolated and converted to 12Vdc for use by the server.

Figure 18 illustrates a variant of the configuration where the PDU converts the voltage. In this configuration, electricity enters the UPS at 480/277Vac and it exits at the same voltage. The electricity then enters the PDU at 480/277Vac, is converted by an autotransformer, and exits at 415/240Vac. Finally, the electricity enters the PSU at 240Vac which galvanically isolates and converts the electricity to 12Vdc for use by the server.

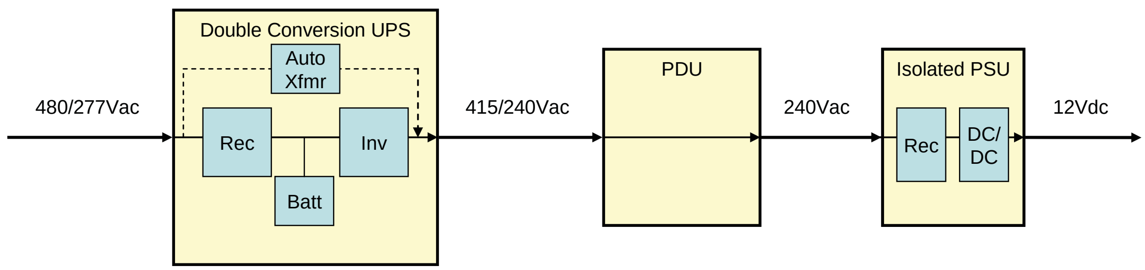

FIGURE 17. 480VAC – 240VAC CONFIGURATION WITH DOUBLE CONVERSION UPS

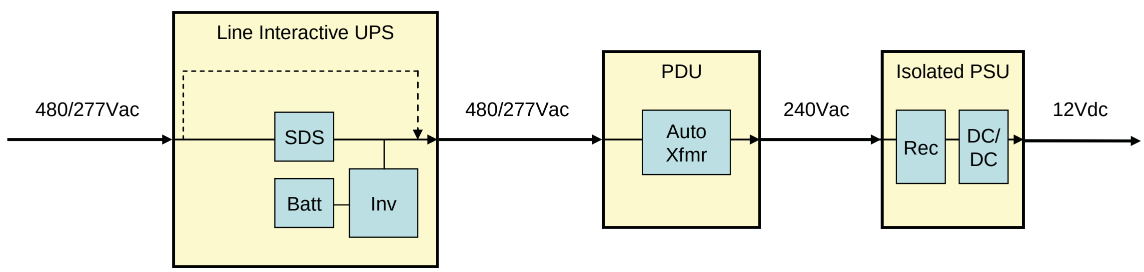

FIGURE 18. 480VAC – 240VAC CONFIGURATION WITH LINE INTERACTIVE UPS

NOTE

The autotransformer loss in the double conversion UPS is accounted for in the model.

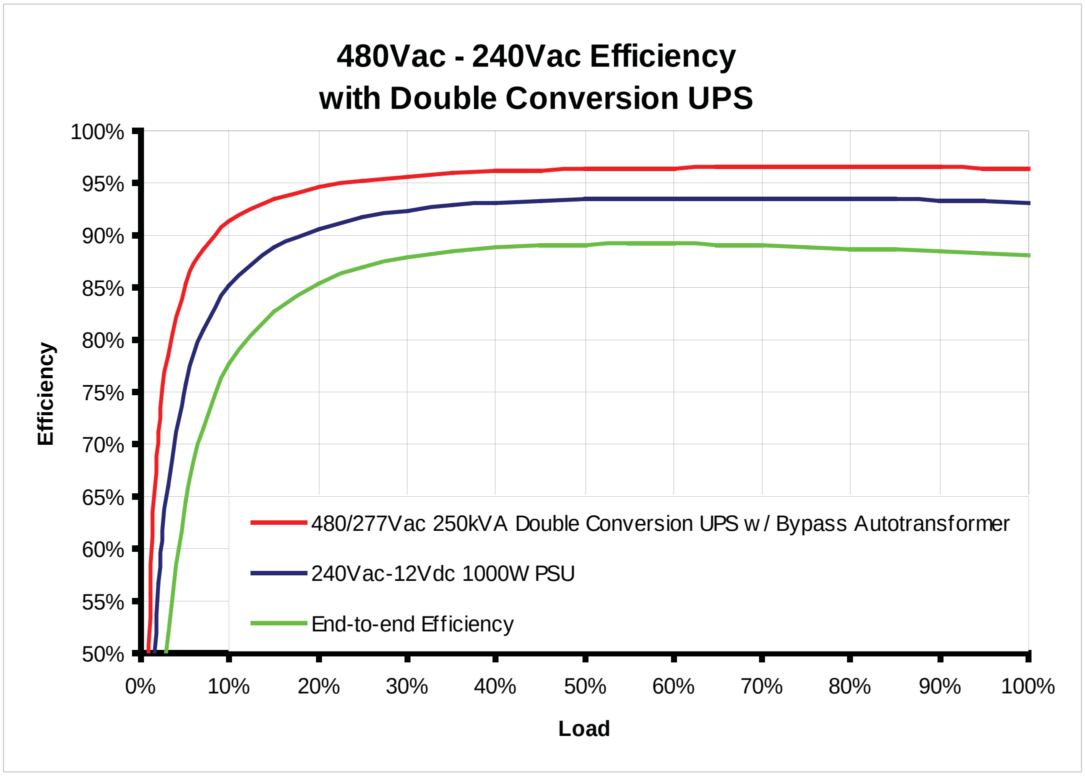

FIGURE 19. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 240VAC WITH DOUBLE CONVERSION UPS

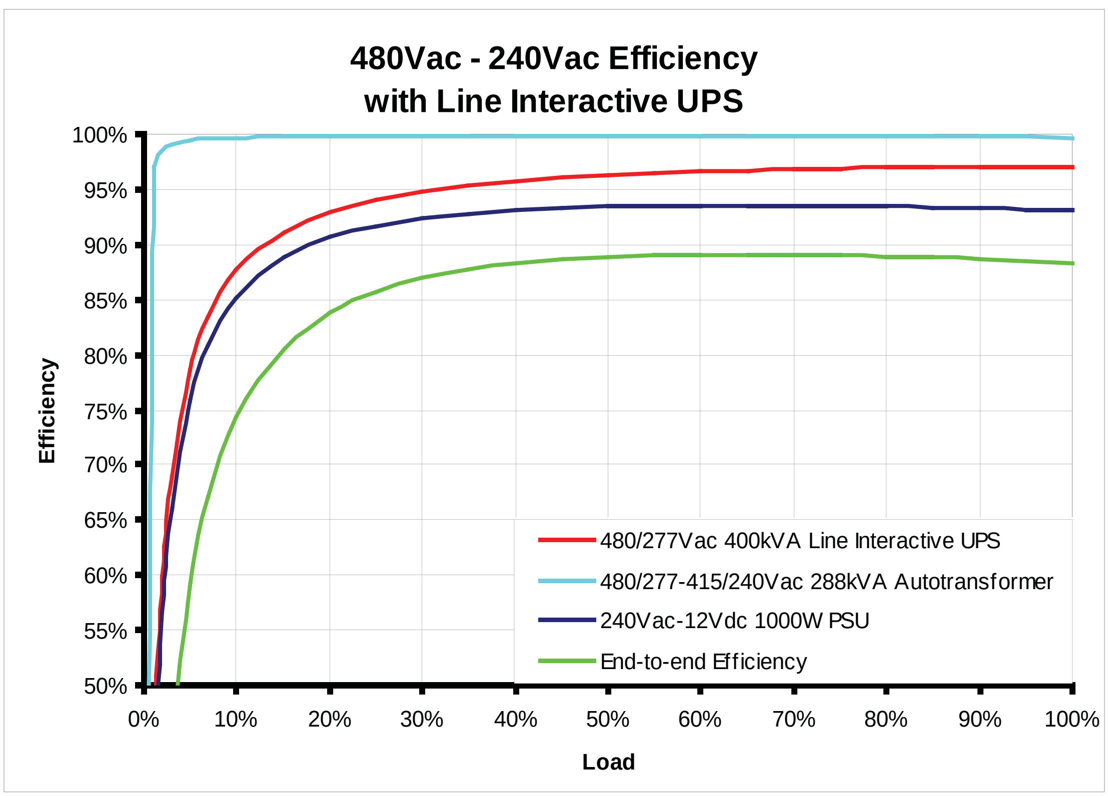

FIGURE 20. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 240VAC WITH LINE INTERACTIVE UPS

Distribution Configuration 5. 480Vac – 48Vdc

This configuration is the standard 48Vdc telecom power distribution system applied to a data center.

In this configuration, electricity enters the DC UPS at 480/277Vac, is converted by the isolated rectifier, and exits at 48Vdc. The electricity then enters the PDU at 48Vdc and exits at the same voltage. Finally, the electricity enters the PSU at 48Vdc and is galvanically isolated and converted to 12Vdc for use by the server.

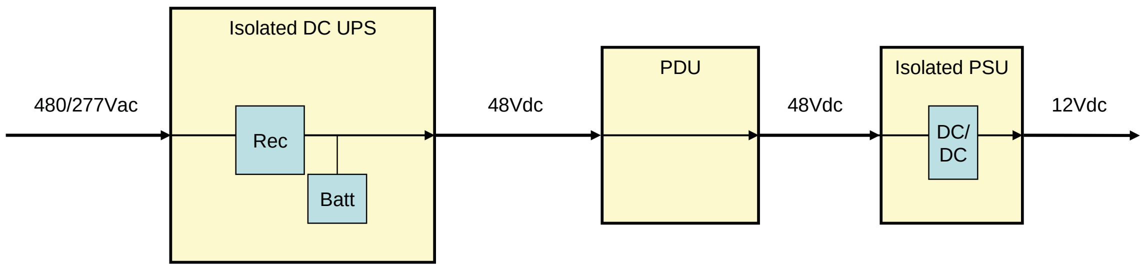

FIGURE 21. 480VAC – 48VDC CONFIGURATION

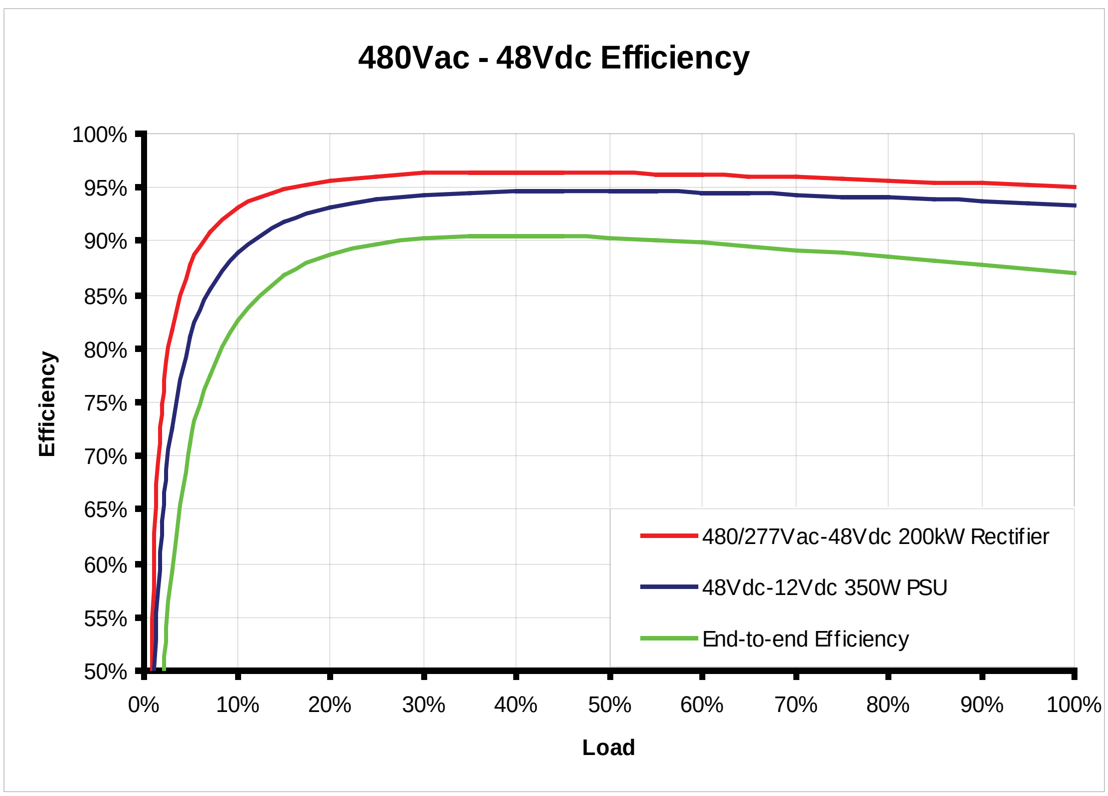

FIGURE 22. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 48VDC

Distribution Configuration 6. 480Vac – 575Vdc – 48Vdc

This configuration uses standard 48Vdc PSUs but distributes 575Vdc to minimize distribution cabling losses and cost.

In this configuration, electricity enters the DC UPS at 480/277Vac, is converted by the isolated rectifier, and exits at 575Vdc. The electricity then enters the PDU at 575Vdc, is converted by the isolated DC/DC converter, and exits at 48Vdc. Finally, the electricity enters the PSU at 48Vdc, where it is galvanically isolated and converted to 12Vdc for use by the server.

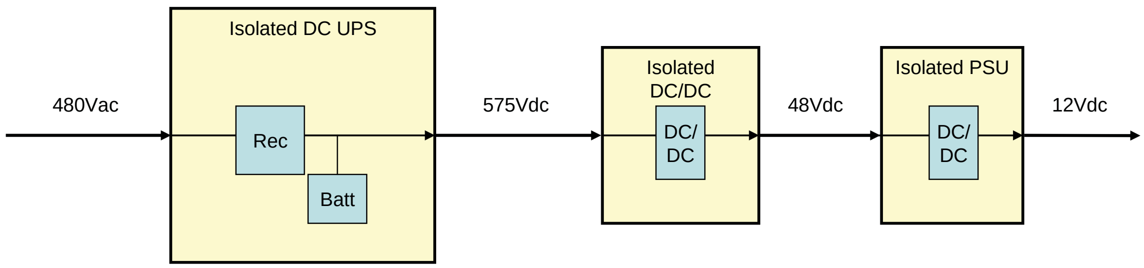

FIGURE 23. 480VAC – 575VDC – 48VDC CONFIGURATION

NOTES

- Because of the lack of published efficiency data for a 575Vdc UPS, photovoltaic inverter data was used to model the UPS. The performance of a photovoltaic inverter operating as a rectifier is similar performance to its operation as an inverter.
- Because of the lack of published efficiency data for an isolated 575Vdc – 48Vdc converter, high efficiency isolated rectifier data was used to model the intermediate converter. A high efficiency rectifier with a 48Vdc output has similar performance to an isolated 575Vdc – 48 Vdc converter.
- The above assumptions yield results that are similar to the available end-to-end performance data on this topology.

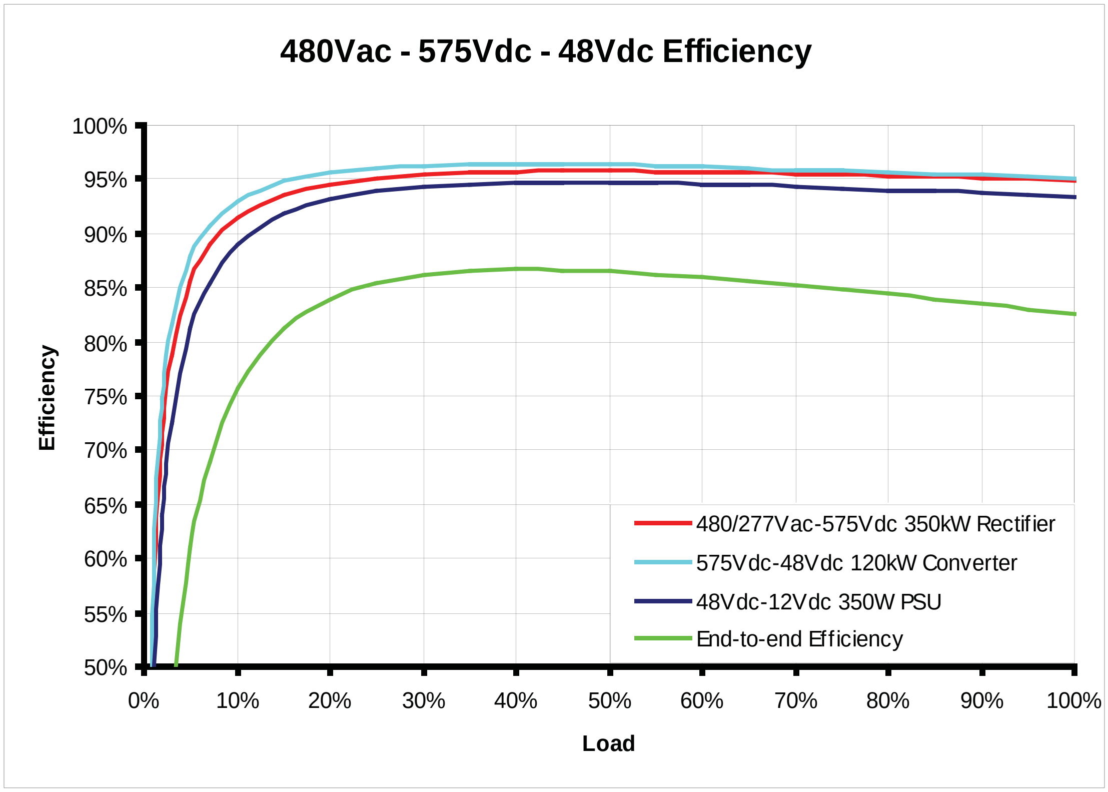

Figure 24. Component and end-to-end efficiency for 480Vac – 575Vdc – 48Vdc

Distribution Configuration 7. 480Vac – 380Vdc

This configuration is similar to the standard 48Vdc telecom power distribution system, but it operates at 380Vdc to minimize distribution cabling losses and cost.

In this configuration, electricity enters the DC UPS at 480/277Vac, is converted by the isolated rectifier, and exits at 380Vdc. The electricity then enters the PDU at 380Vdc and exits at the same voltage. Finally, the electricity enters the PSU at 380Vdc, where it is galvanically isolated and converted to 12Vdc for use by the server.

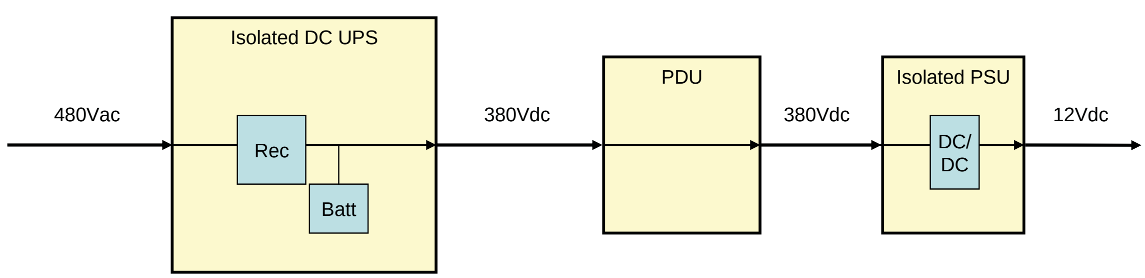

FIGURE 25. 480VAC – 380VDC CONFIGURATION

NOTES

• Because no production level 380Vdc UPSs were available, photovoltaic inverter data was used to model the UPS. The performance of a photovoltaic inverter operating as a rectifier is similar performance to its operation as an inverter.

• The PSU for this system was an AC production unit appropriately modified to operate from 380Vdc.

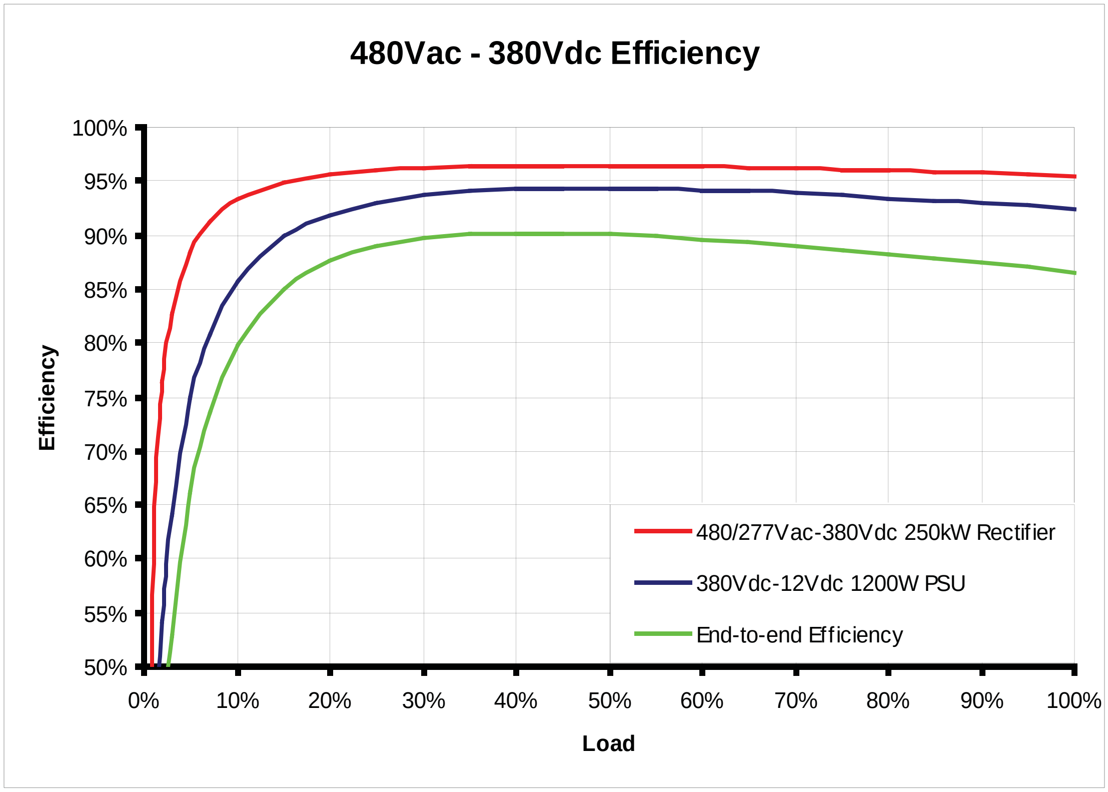

FIGURE 26. COMPONENT AND END-TO-END EFFICIENCY FOR 480VAC – 380VDC

Overall Configuration Comparison

The following figures present the end-to-end efficiency curves for the various configurations. Figure 27 shows all of the contemporary implementations of the various configurations along with the legacy implementation of the 480Vac – 208Vac configuration. Figure 28 shows only the contemporary configuration implementations. (See Appendix: Power Distribution Configuration Comparison Charts for more detailed comparisons of the various configurations.)

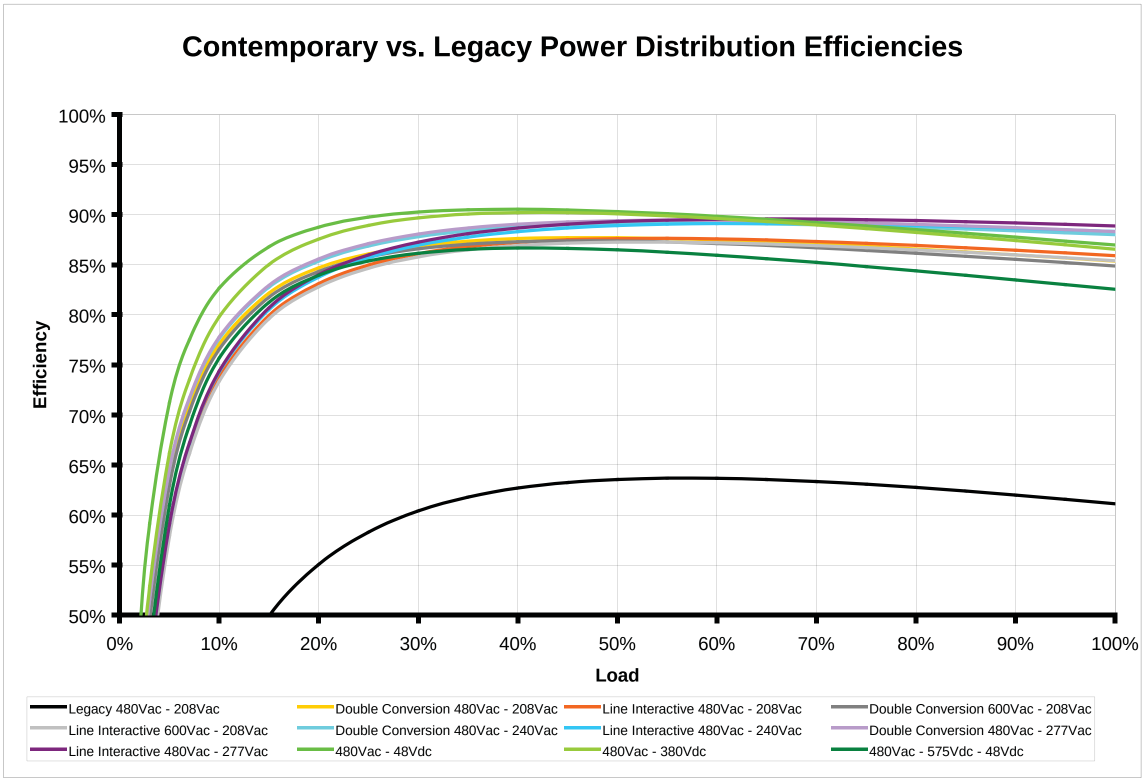

FIGURE 27. END-TO-END EFFICIENCY COMPARISON OF ALL CONFIGURATIONS

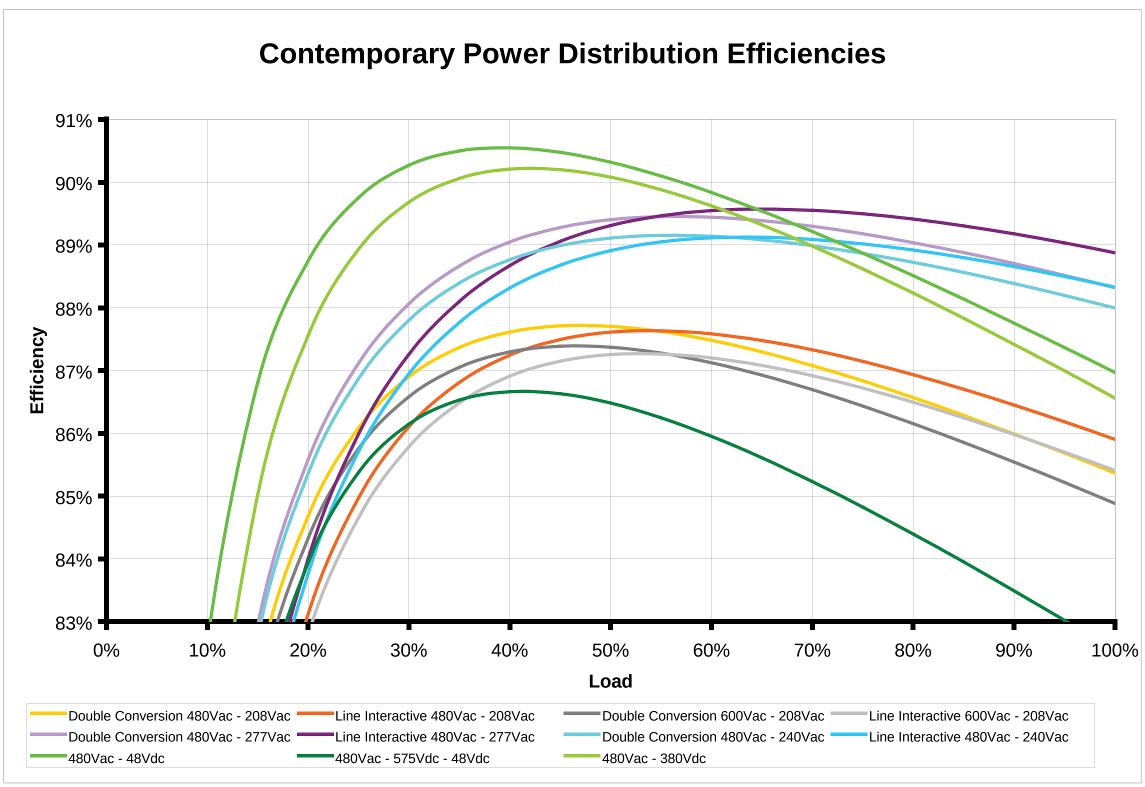

FIGURE 28. END-TO-END EFFICIENCY COMPARISON, EXCLUDING LEGACY 480VAC – 208VAC

Component Efficiency Comparison

Each of the following figures shows a comparison between all the components that perform similar functions in the various configurations. Note that the scale of the y-axis varies from figure to figure.

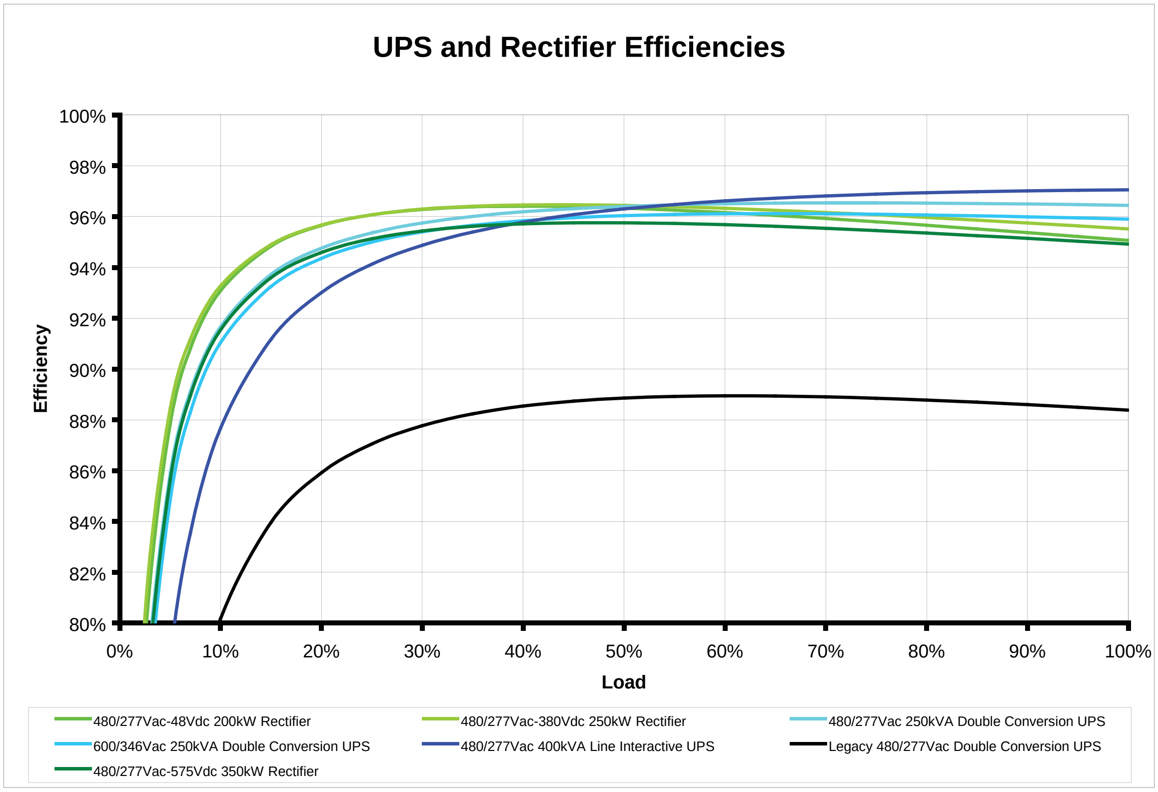

FIGURE 29. AC UPS AND DC RECTIFIER EFFICIENCY COMPARISON

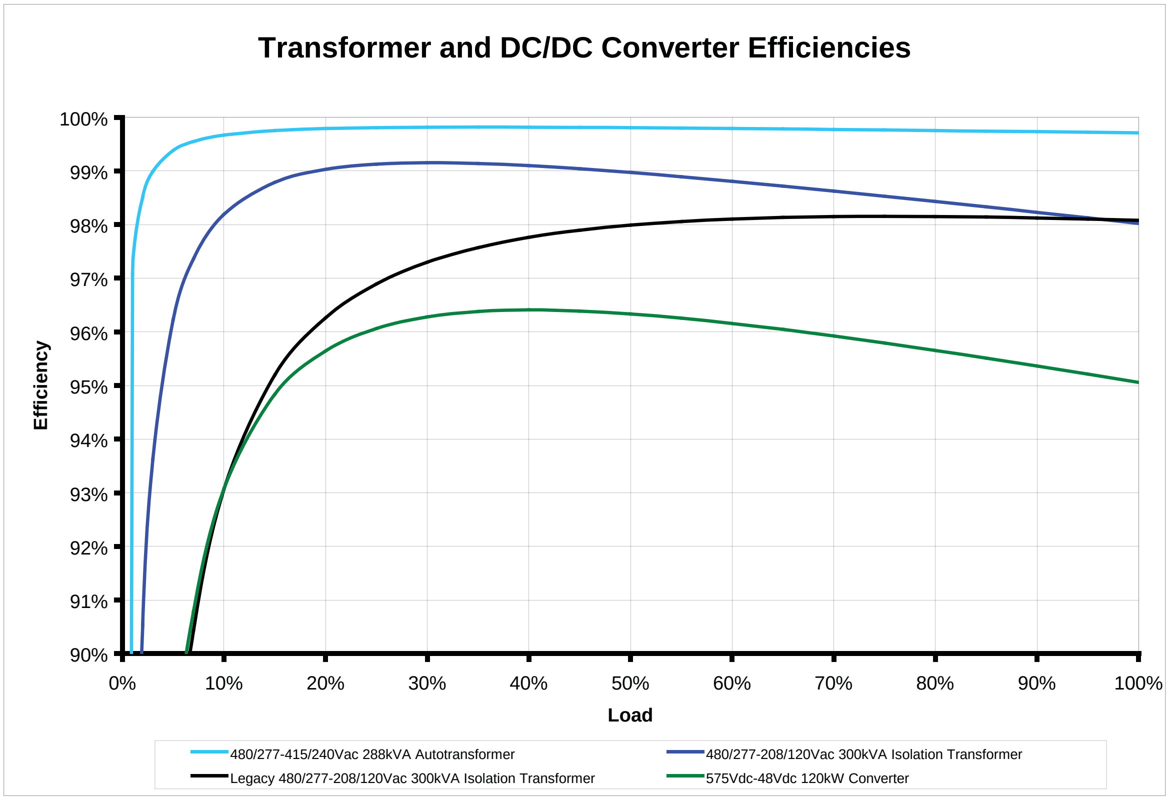

FIGURE 30. TRANSFORMER AND DC/DC CONVERTER EFFICIENCY COMPARISON

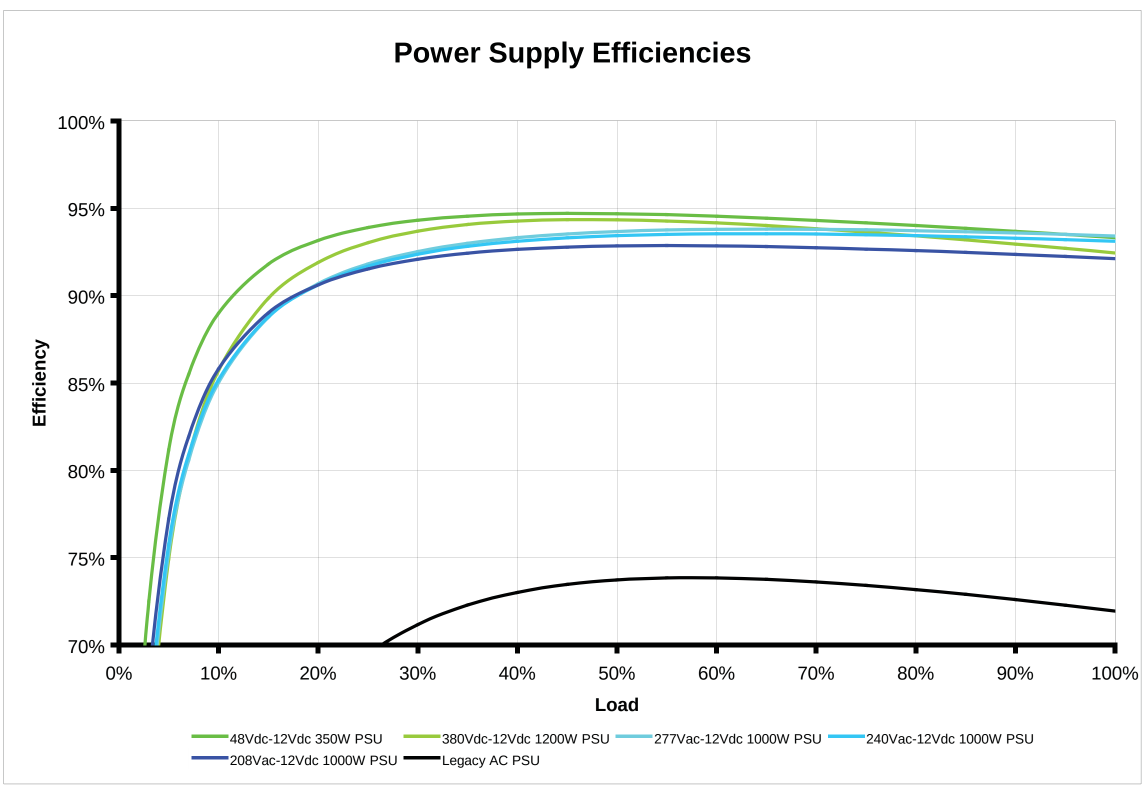

FIGURE 31. POWER SUPPLY EFFICIENCY COMPARISON

CONCLUSIONS

Figure 27 illustrates:

• All contemporary configuration implementations are approximately 25% more efficient than the legacy implementation of the 480Vac – 208Vac system.

• The contemporary double conversion implementation of the 480Vac – 208Vac configuration is approximately 25% more efficient than the legacy implementation; a difference that can only be attributed to component improvements.

Figure 28 illustrates:

• The end-to-end efficiencies of all of the contemporary implementations are generally within about 5% of each other at loads above 20%.

• No single configuration provides the highest efficiency at every load; DC configurations prevail at low loads and AC configurations prevail at high loads.

• The highest efficiency AC and DC configurations are within 1% to 2% of each other and are only 2% to 3% better than double conversion 480Vac – 208Vac over the majority of the load range.

• AC Configurations that eliminate isolation transformers and operate the servers at higher voltages are 1% to 2% more efficient than configurations that use the same components but include isolation transformers and operate the servers at 208Vac.

Figure 29 illustrates:

• UPSs are currently available that are 7% to 8% more efficient than an average UPS of the past.

• The best known AC UPSs and DC rectifiers provide similar efficiencies, peaking at approximately 96%.

Figure 30 illustrates:

• Eliminating an isolation transformer or replacing it with an autotransformer, improves efficiency by approximately 1% to 1.5%.

• Isolation transformers are currently available that are 2% to 3% more efficient at low loads than an average transformer of the past.

• The active DC/DC converter used in this analysis is approximately 3% less efficient than a comparable high efficiency isolation transformer.

Figure 31 illustrates:

• Power supplies are currently available that are approximately 20% more efficient than an average power supply of the past.

• The best known AC UPSs and DC power supplies provide similar efficiencies, peaking at approximately 94%.

• The highest efficiency AC and DC power supplies are within 1.5% of each other over the majority of the load range.

SUMMARY

Data center power distribution topologies, created with the best currently available components, have the potential to delivery end-to-end efficiencies in excess of 85% over a wide operating range. When considering efficiency, there is no single AC or DC configuration that provides superior efficiency at all loads or in all situations. The efficiency differences among the contemporary implementations are relatively minor. All components and configurations have undergone great efficiency improvements in the last decade and will likely continue to improve. When evaluating data center power distribution configurations, multiple factors such as reliability, equipment availability, safety and cost must be considered in addition to efficiency. Regardless of the topology, history shows that proper component selection is the dominant factor in delivering high efficiency. Accordingly, when high efficiency is desired, great care should be exercised in the component selection process.

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APPENDIX: POWER DISTRIBUTION CONFIGURATION COMPARISON CHARTS

Each of the following figures shows a comparison between a baseline configuration and all other alternatives. The baseline configuration is shown at 0%. Positive improvements indicate that a given configuration is more efficient than the baseline. Negative performance indicate that a given configuration is less efficient than the baseline. Note that the scale and the zero point of the y-axis vary from figure to figure.

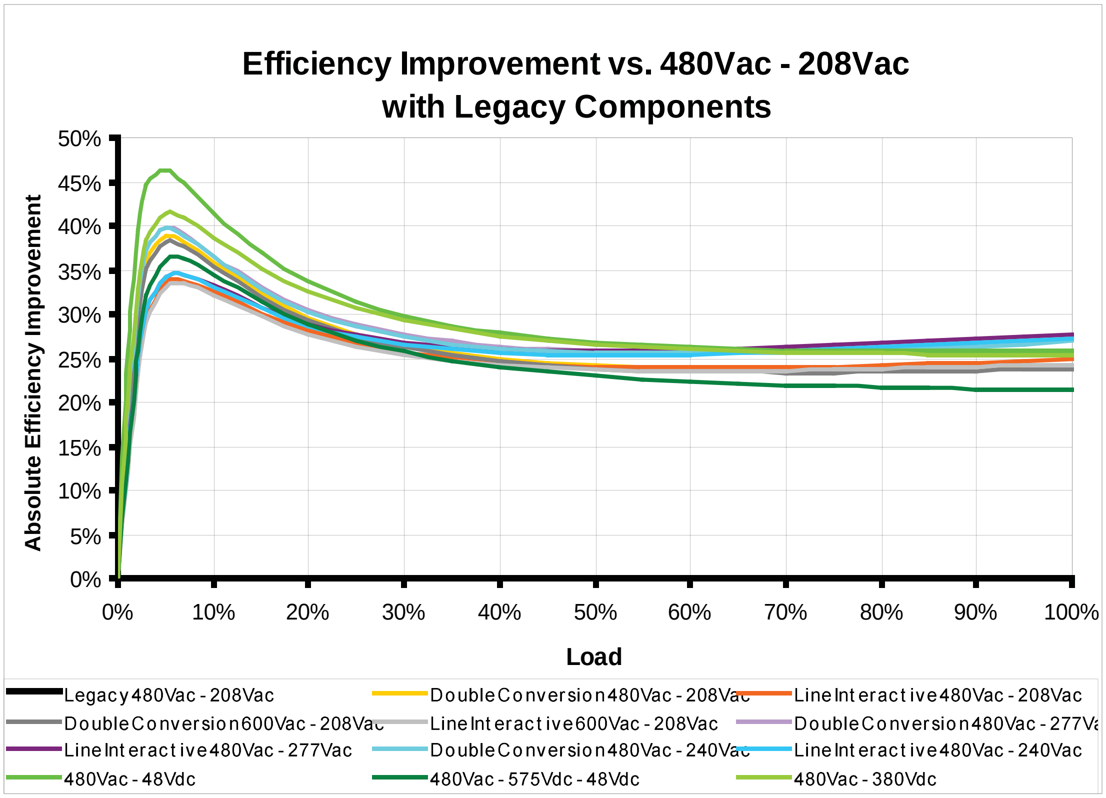

FIGURE 32. EFFICIENCY COMPARISON VS. LEGACY 480VAC – 208VAC

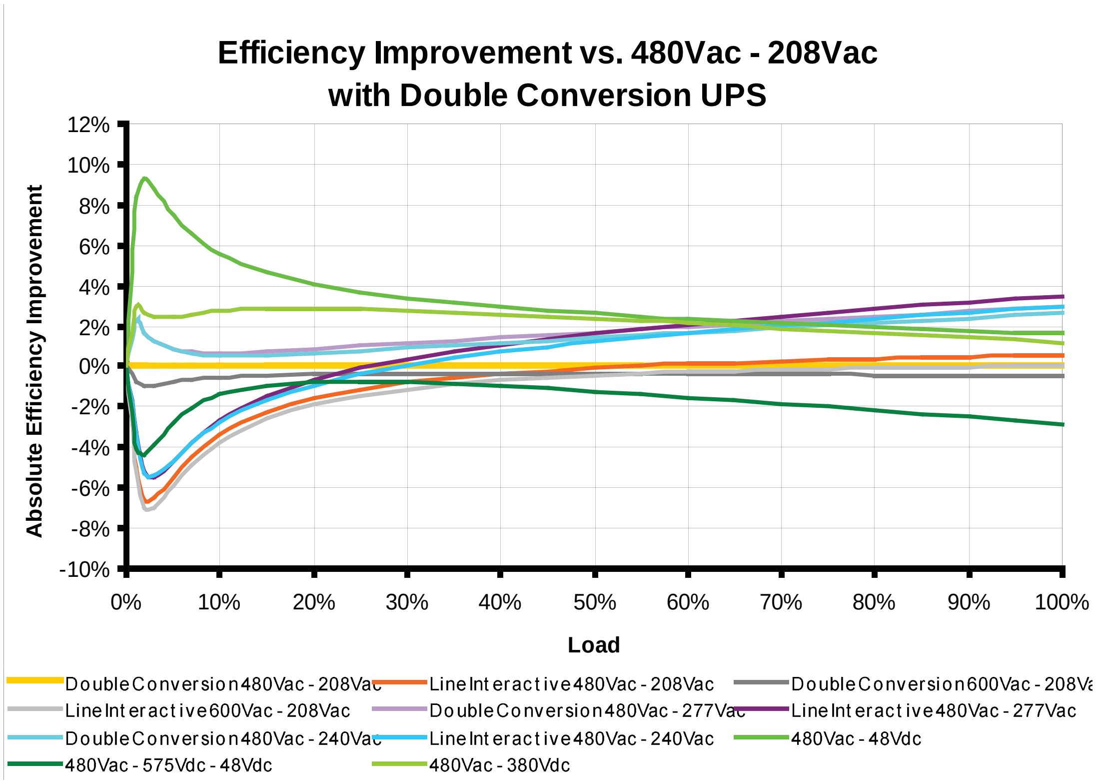

FIGURE 33. EFFICIENCY COMPARISON VS. 480VAC – 208VAC WITH DOUBLE CONVERSION UPS

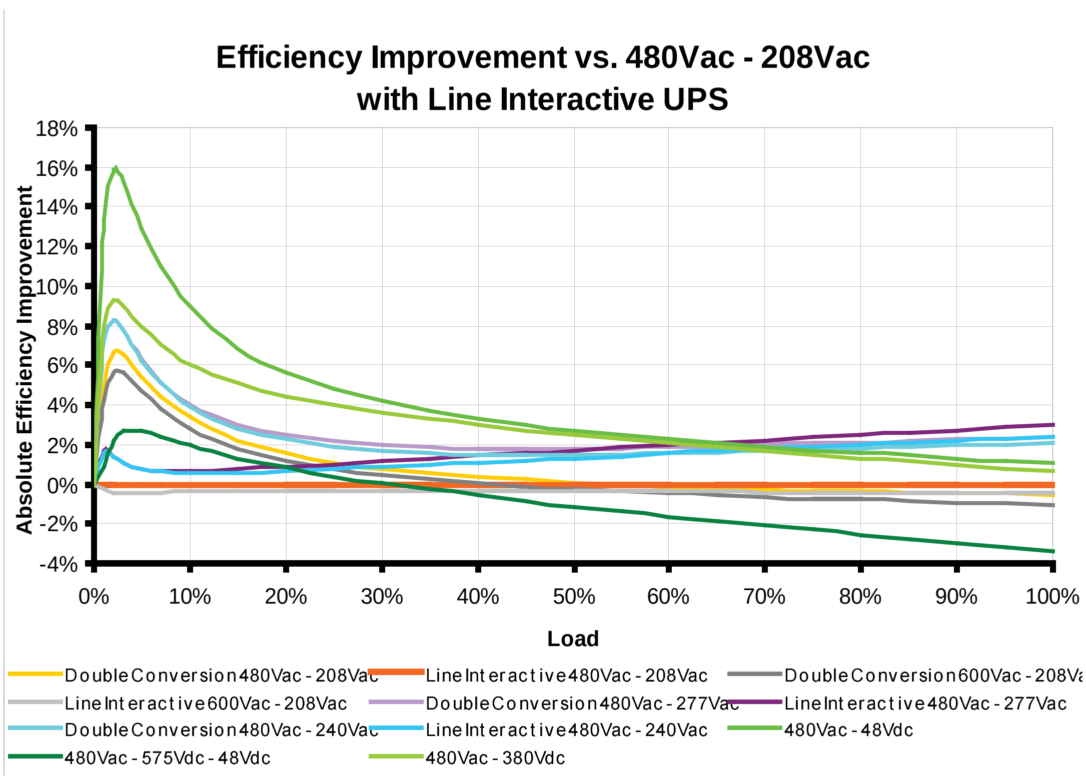

FIGURE 34. EFFICIENCY COMPARISON VS. 480VAC – 208VAC WITH LINE INTERACTIVE UPS

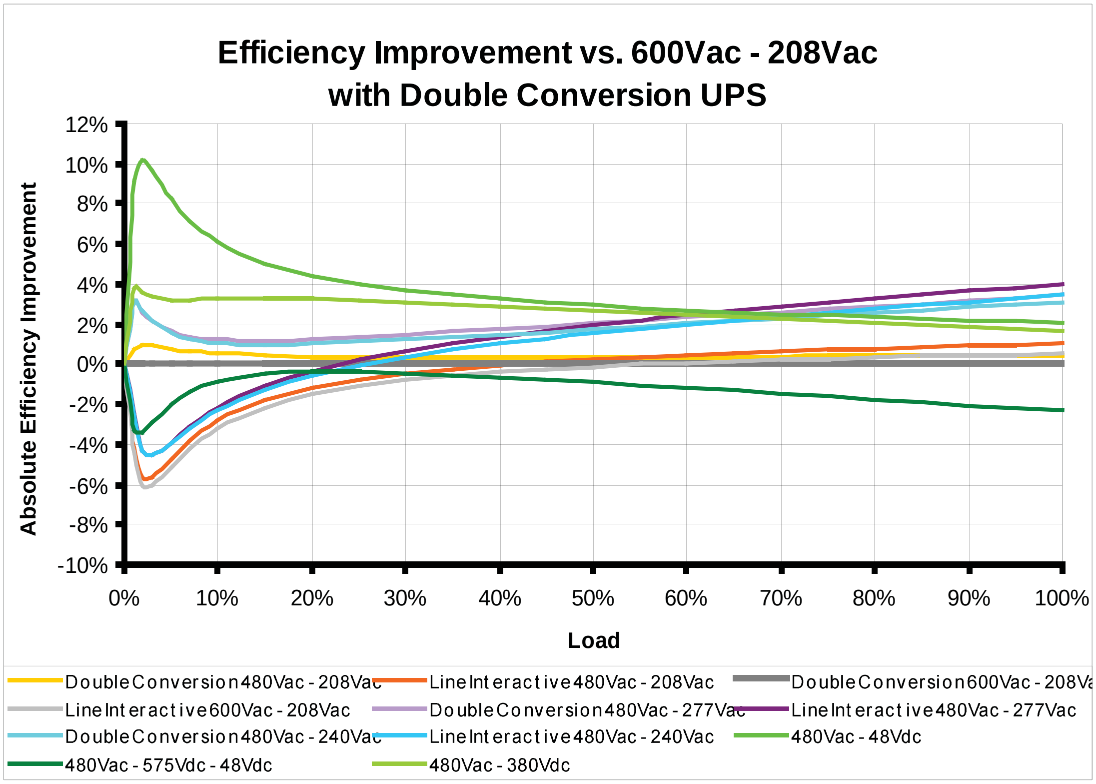

FIGURE 35. EFFICIENCY COMPARISON VS. 600VAC - 208VAC WITH DOUBLE CONVERSION UPS

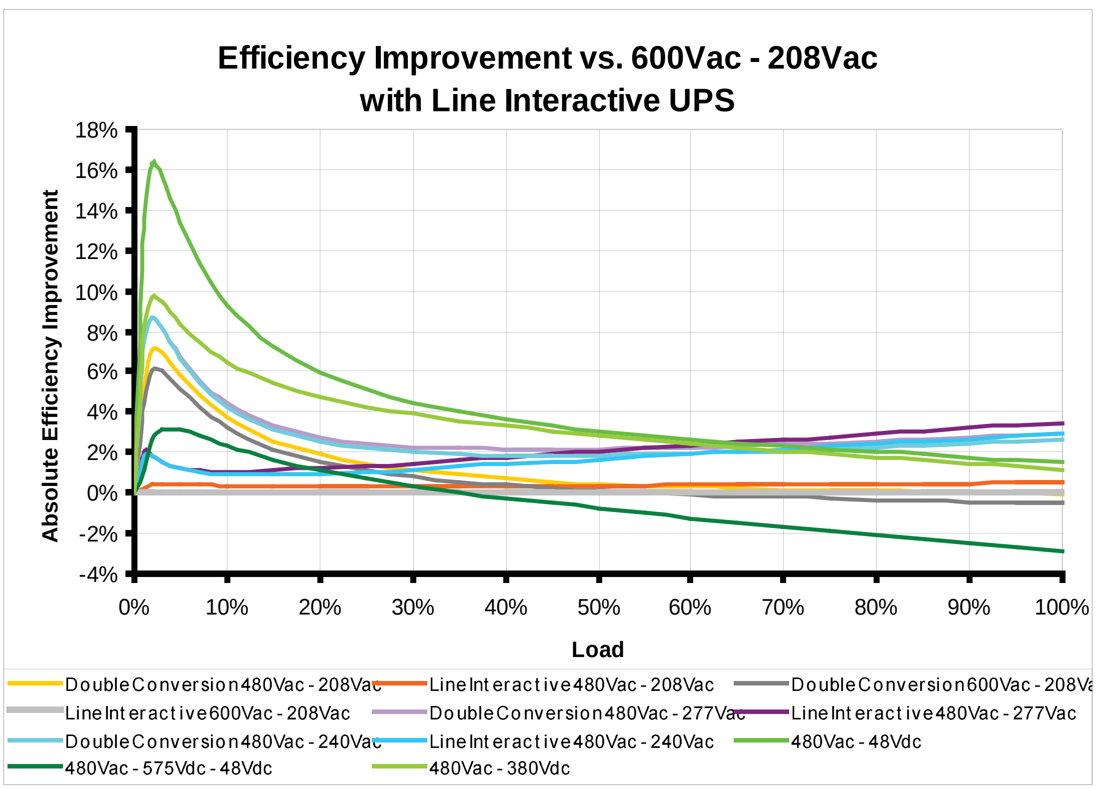

FIGURE 36. EFFICIENCY COMPARISON VS. 600VAC – 208VAC WITH LINE INTERACTIVE UPS

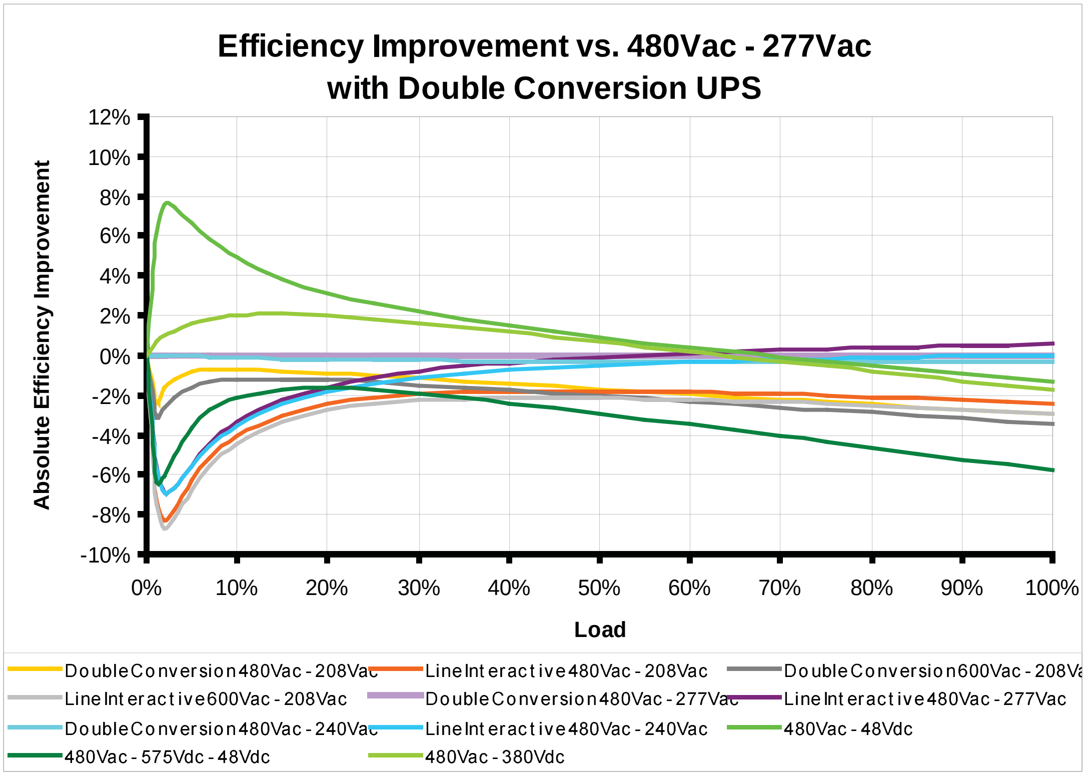

FIGURE 37. EFFICIENCY COMPARISON VS. 480VAC – 277VAC WITH DOUBLE CON VERSION UPS

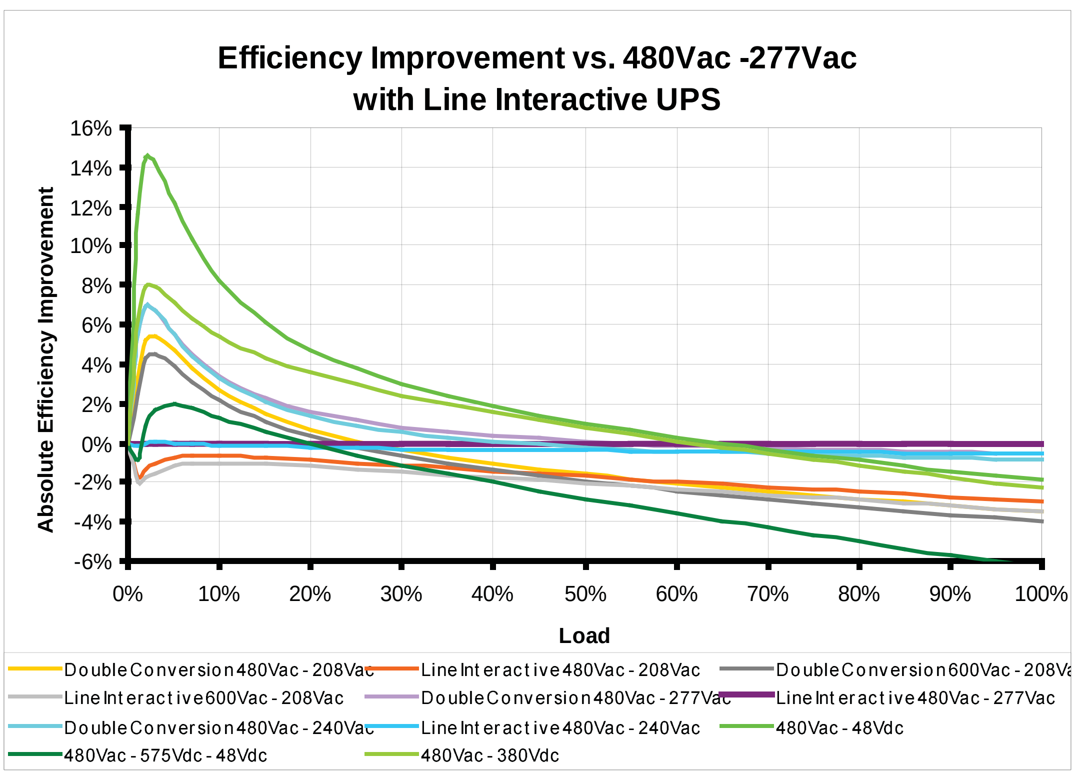

FIGURE 38. EFFICIENCY COMPARISON VS. 480VAC – 277VAC WITH LINE INTERACTIVE UPS

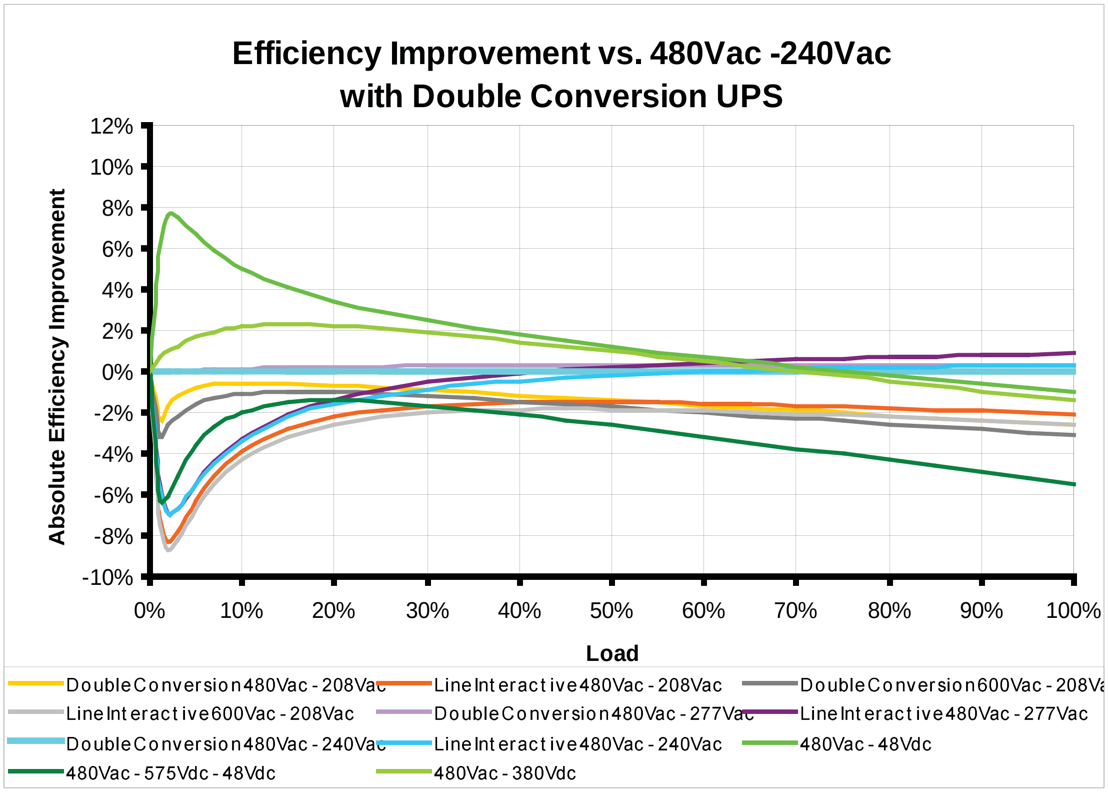

FIGURE 39. EFFICIENCY COMPARISON VS. 480VAC – 240VAC WITH DOUBLE CONVERSION UPS

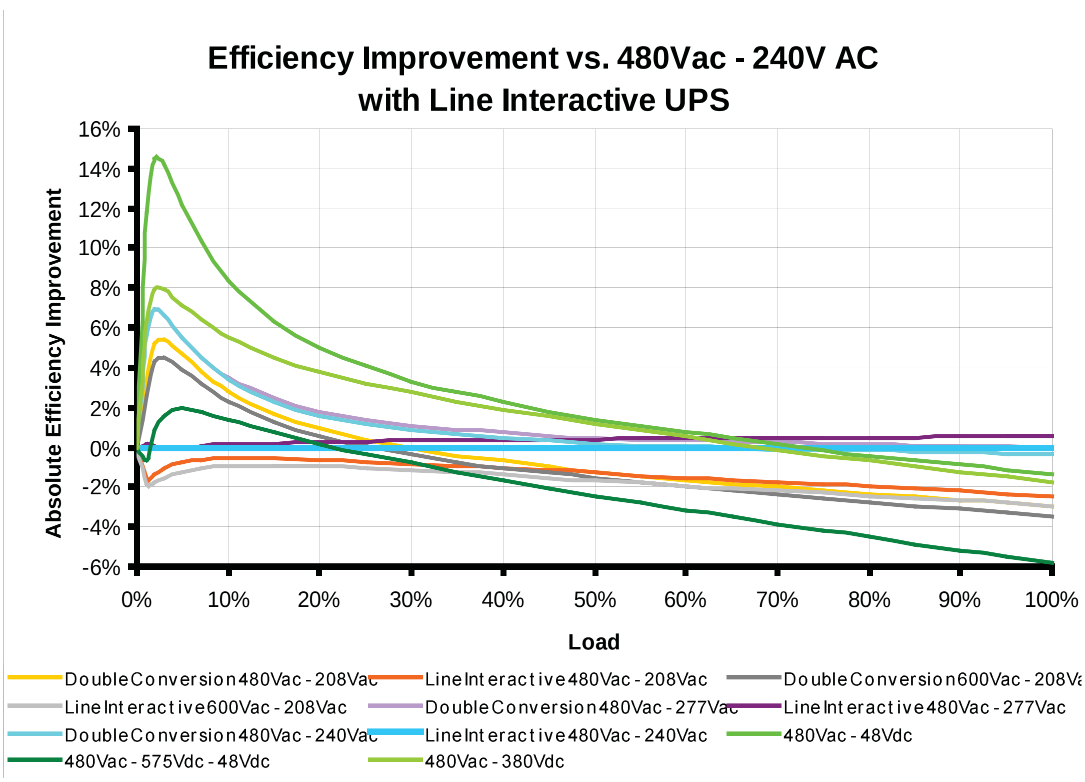

FIGURE 40. EFFICIENCY COMPARISON VS. 480VAC – 240VAC WITH LINE INTERACTIVE UPS

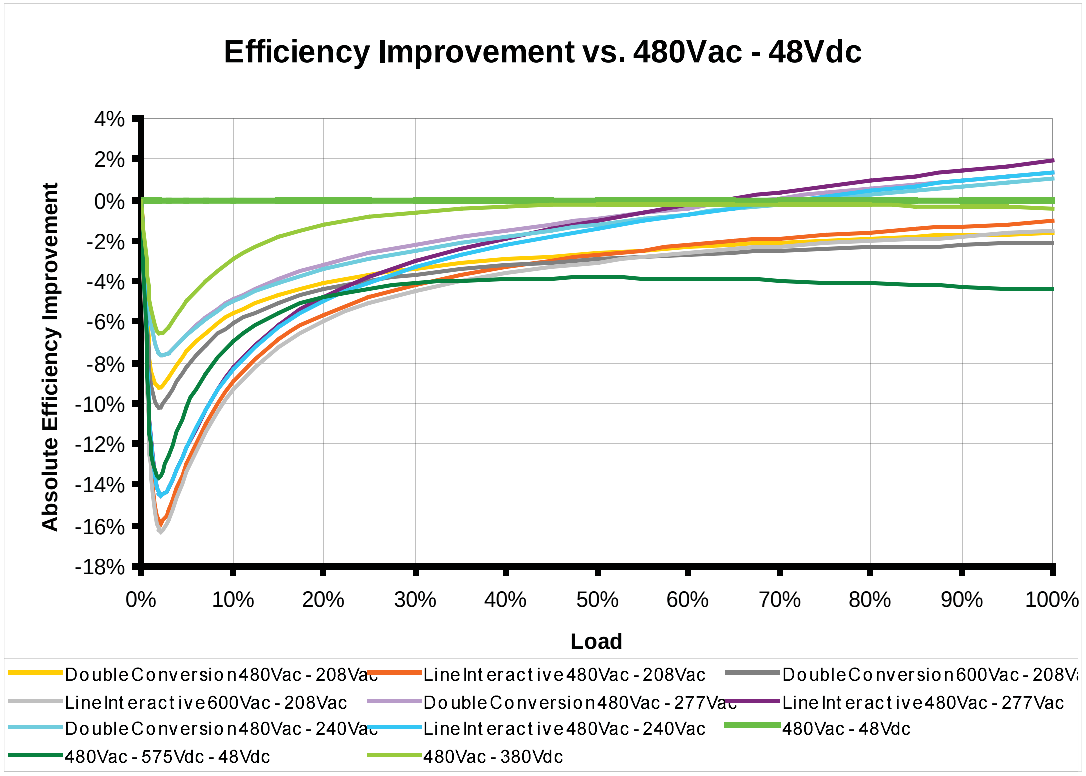

FIGURE 41. EFFICIENCY COMPARISON VS. 480VAC – 48VDC

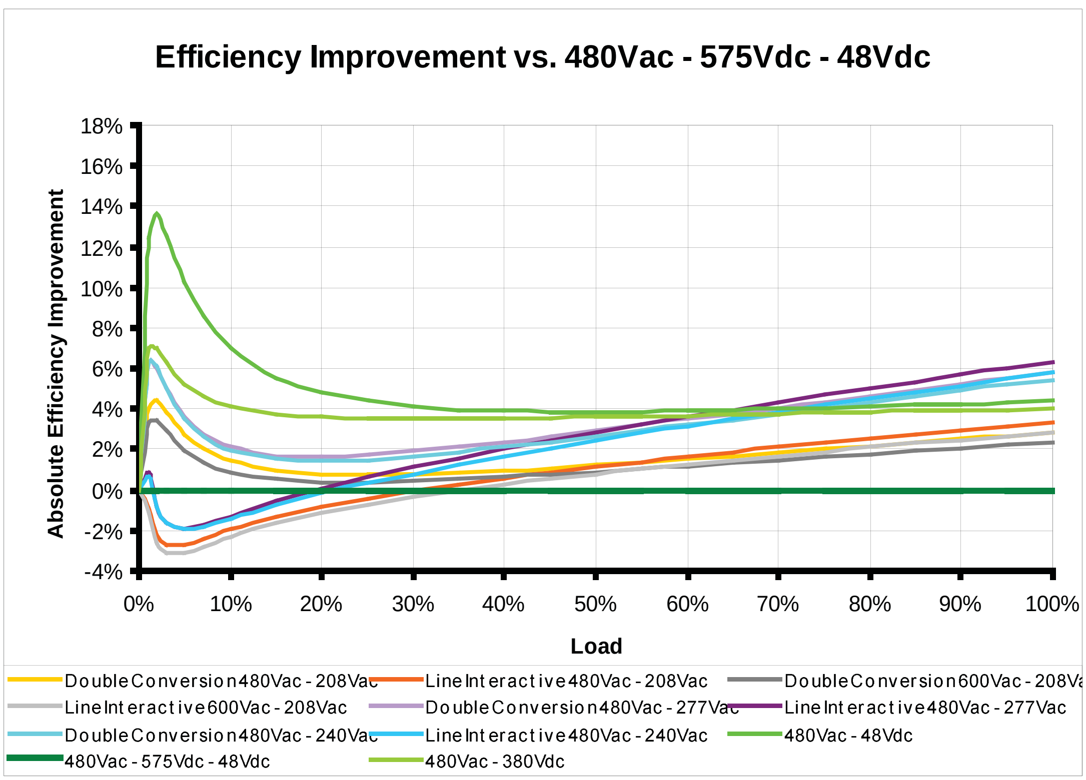

FIGURE 42. EFFICIENCY COMPARISON VS. 480VAC – 575VDC – 48VDC

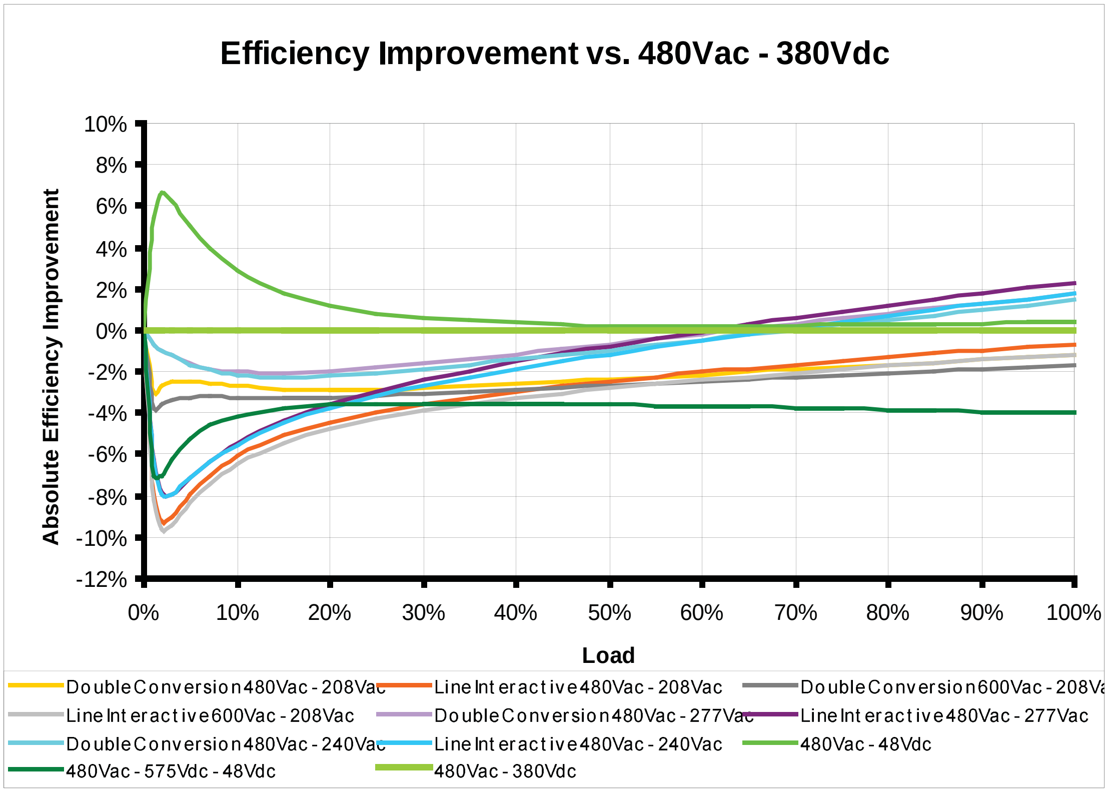

FIGURE 43. EFFICIENCY COMPARISON VS. 480VAC – 380VDC

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