

THYCON

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High Energy Density Distribution Appraisal



Executive Summary

This paper discusses the capital cost and operational efficiency advantages that adopting higher voltage, three wire reticulation can achieve.

UPS Systems specifically designed for higher voltage applications are more efficient than lower voltage systems while delivering greater power to downstream loads for each given ampere of current.

The application of voltages at the upper limit of the Low Voltage (LV) threshold allows conventional switchgear and cabling to be used, avoiding the costs and expense of medium & high voltage (MV & HV) equipment.

The utilisation of Triplen Isolation Step Down transformers in the final stage of the reticulation ensure a clean MEN is provided to the critical load and penetration of harmonic currents back through the supply is restricted.

Triplen Harmonics

Triplen Harmonics Currents dominate Switch Mode Power Supply (SMPS) loads and have the unique property of adding in the neutral conductor. This characteristic may result in unexpected overloading of the neutrals and increased voltage drop at the load.

A delta - star transformer is often believed to be the solution to dealing with triplen harmonics, however it is better to specify a Triplen Transformer, which also prevents migration of third harmonic voltages across the primary and secondary windings.



3 Wire Reticulation

Three phase power transmission was adopted to maximize the efficiency of transmission over long distances for the minimal copper cost.

The neutral conductor is not necessary for three phase power distribution and is only required when connecting single phase loads. As such, the installation of neutral cabling is not necessary for much of the transmission distance in a Data Centre situation.

True three phase UPS systems also do not require a neutral conductor, therefore making their installation an unnecessary cost.

Adopting a three wire distribution model allows capital infrastructure costs to be significantly reduced.

960V Distribution

Distribution Levels are grouped into four main categories:

- | | |
|---------------------------|------------------|
| • Extra Low Voltage (ELV) | 0 to 50VAC |
| • Low Voltage (LV) | 50V to 1000VAC |
| • Medium Voltage (MV) | 1000VAC to 38kV |
| • High Voltage (HV) | 38kV and Greater |

In Australia, distribution in Data Centres has traditionally focused on Low Voltage 415/240V reticulation as per AS 60038:2000. Generally, implementation of voltage reticulation at each subsequent voltage class, requires greater risk management controls and hence greater capital cost.

Considerable efficiency and performance gains may be realized by implementing distribution at the upper limit of the LV category.

Thycon has utilized this approach for many years in distributing 60Hz Shore to Ship and 400Hz Aircraft power, with the higher operating voltages permitting greater power densities and avoiding excessive infrastructure costs.

Power is defined as the product of the voltage and current. An increase in the operating voltage results in a linear increase in the power flowing through a system. As such, increasing the supply voltage from 240/415 to 554/960 represents an increase in power density of 230% for effectively the same infrastructure.



Greater Operating Efficiency

By adopting a three wire, 960V distribution to the UPS input & output, efficiency improvements can be realized across the entire system.

UPS Operation

A three wire, 960V UPS rectifier will provide higher efficiency performance, as current draw reduces for a given power output. This is due to both power conductor and semi-conductor component losses diminishing.

On State Volt Drop Across Semi-Conductor Components

On average, a thyristor exhibits an on-state voltage drop of 1.4V. The power loss across the device is the product of the conduction current and on state voltage drop. By reducing the current the thyristor losses are directly reduced.

Other power electronic components, such as IGBT typically exhibit a significantly higher on state voltage drop (around 2.8V), and therefore worse efficiencies exist in their implementation.

I²R Losses Across Power Conductors

Throughout the UPS power circuit, all conducting elements have impedance. Any current flowing will therefore lose energy in accordance with the formula: $\text{current}^2 \times \text{impedance}$. As such doubling the voltage, halves the current which results in a 75% transmission efficiency benefit.

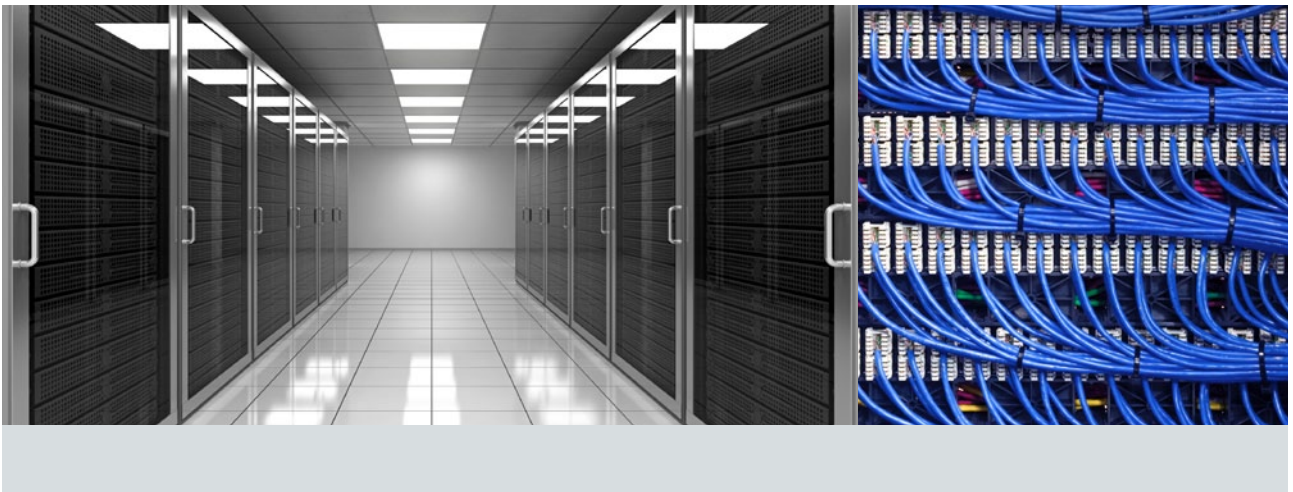
UPS Output Transformer

The UPS output transformer has two major sources of loss:

- Core Losses
- Winding Losses

In general, these losses are a function of the transformer construction, and are relatively constant for a given transformer KVA rating.

A neutral forming output transformer, essential in four (4) wire systems is not required in a three wire, higher voltage system and under certain design conditions may be eliminated to achieve higher overall system efficiencies. The elimination of the transformer can reduce system losses by a further 1% to 2%.



Distribution System

Total losses across the distribution network will be reduced due to the higher operating voltage. This occurs since the total current flowing in the network is reduced by 43% which equates to a reduction in cable I²R losses of 18.75% in comparison to a 415V system if the same cable is used.

A more significant benefit is the greater utilization of LV infrastructure.

For example, a 1000A, three pole circuit breaker operating at 240V/415V can supply a load of:

$$3 \times 1000A \times 240V = 720kVA,$$

In comparison, the same circuit breaker, if operating at 960V/554V can supply a load of:

$$3 \times 1000A \times 554V = 1660kVA$$

This is 2.3 times the previous load using the same infrastructure components.

With regards to cabling, most cable used in LV situations is rated to 0.6/1kV in compliance with AS/NZS 5000.1 or IEC 60502.1 and is therefore suitable for operation at 960V.

Cooling Losses

For every dollar of energy saved, cooling costs are reduced, effectively doubling the overall efficiency saving. This efficiency saving occurs not only at the UPS but throughout the entire reticulation.

Reduced Footprint/Greater Density

With operation at higher voltage levels, the corresponding reduction in current, allows the size of many components in the system to be reduced for the same kVA capacity.

This directly relates to the improved power densities achievable with a higher LV voltage approach. Typically you would expect the circuit breaker frame size to reduce by one to two sizes at 960V in comparison to 415V. This can have a significant impact on the overall footprint of switchboard and cable reticulation throughout a building.

This situation changes when moving to MV & HV switchboards, which require greater clearances and specialized protection devices to achieve appropriate fault containment. This actually adds to the size and cost of the switchboard and is one reason to carefully consider operating a site in the MV or HV range.



Triplen Step Down Isolation Transformer

The final reticulation at the rack level must still be performed at 415/240V. To achieve this triplen transformers are employed at the PDU level to step down the voltage and provide a clean neutral for single phase IT loads.

It is important that the Triplen Transformer is located as close as possible to the IT load to minimize harmonic disturbances on the supply. The transformers perform the following functions:

- Step Down 960Vac to 415Vac
- Provide a clean MEN neutral for the critical IT load
- Isolate all balanced triplen harmonic currents from penetrating back up the supply

In addition, by providing a method of power Import / Export, each transformer can be isolated and maintained without impacting on supply to the downstream load. By providing a common, fresh neutral on the load side, and not requiring a neutral on the 960V side, the requirement for 4 Pole STS units is eliminated, which reduces complexity and removes a further source of risk in the Data Centre.

Triplen Transformers perform an important role in modern data centres by providing a passive barrier to the penetration of balanced triplen harmonic currents which are particularly prevalent in sites with high switched mode power supply (SMPS) loads.

Triplen harmonics include the third harmonic and all integer multiples thereof. This includes the 3, 6, 9, 12, 15, etc.

Triplen harmonics are particularly troublesome because they sum in the neutral conductor. This is different to all other harmonics which cancel in the neutral. This property can have severe impacts on power quality including:

- Overloaded Neutral Conductors
- Increased Voltage Drop between the load and supply resulting in lower operating voltage at the load
- Flattening of the voltage waveform resulting in an increase in the operating temperature of connected equipment and increased power supply failure rates
- Increased Earth-Neutral Voltage separation at the load. This can impact communication data rates

By including a passive Triplen transformer, the above issues are negated, neutral currents are eliminated and the impact on the voltage wave shape and size is addressed. In addition, the creation of a clean, isolated neutral ensures that external faults that effect the building neutral are unable to impact the critical load.

Triplen transformers may be installed in the PDU or integrated into a TSTS (Triplen Static Transfer Switch).

[illegible]



Comparison of an A/B/C Dual Cord 960V VS 415V 3.75MVA Data Centre

Drawing L01492 shows a three way distributed UPS reticulation. Depending on the level of fault tolerance specified, the system may normally be loaded to 833kVA or 1250kVA load.

At a maximum normal load of 833kVA the system is able to withstand both the loss of one UPS out of each pair as well as the loss of any one distribution path. Should the load increase to 1250kVA per UPS, the system is fault tolerant such that it can withstand either the loss of one of each UPS pair or the loss of one distribution path.

Downstream of each supply we have shown TSTS Triplen Static Transfer Switches. These devices incorporate a triplen harmonic transformer and STS in the one integrated device. The 3 wire design also eliminates a need for 4 pole STS units.

In a more simplified design the TSTS units could be replaced with step down triplen transformers. In either case the triplen transformer should be located as close to the load as possible.

To provide a maintenance wrap-around facility for each TSTS, an import/export circuit breaker configuration has been shown. The concept of the import/export is to provide an alternative clean power source for the load rather than relying on a Generator or Mains Bypass facility.

Cost Considerations

The drawing shows circuit breaker sizes based on a 415V and 960V reticulation.

In each case the use of 960V has resulted in a dramatic reduction in circuit breaker and cable sizes. Further the elimination of the neutral conductor for the 960V reticulation, the smaller ladder/tray requirement and the reduction in the installation labour cost all combine to make the 960V reticulation more cost effective.

When Thycon had the two scenarios above costed, the following quotations were provided from a well established electrical contractor.

415V Reticulation –
\$1,752,450 ex GST

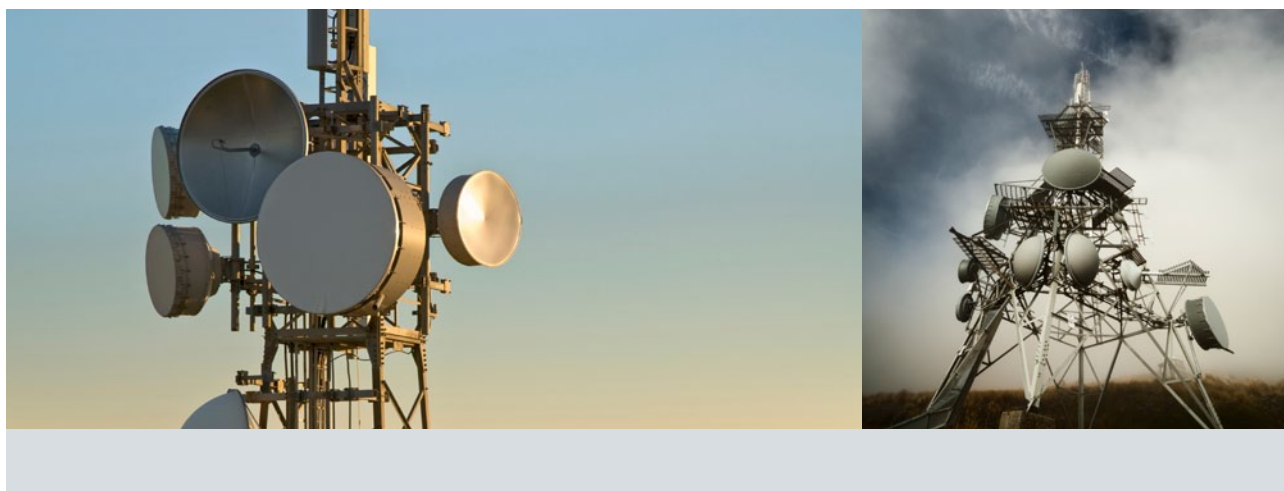
960V Reticulation –
\$693,453 ex GST



A breakdown of these figures is provided.

	415V	960V	Saving
UPS Input Switchboard Cost	\$120,550	\$50,210	\$70,340
UPS Output Switchboard Cost	\$77,591	\$32,941	\$44,650
Cabling Costs	\$386,000	\$148,000	\$238,000
Total per System	\$584,150	\$231,151	\$352,999
Site Cost	\$1,752,450	\$693,453	\$1,058,997

These costs would indicate that we are paying a significant premium for adopting a 415V reticulation. In terms of the capital cost of the UPS & TSTS equipment, there is very little cost difference between 960Vac and conventional 415Vac units.



Efficiency Considerations

The operation of equipment at higher voltage levels is inherently more efficient than at lower operating voltages, however an analysis is required to choose between lower upfront capital versus higher lifetime efficiency gains in reticulation infrastructure.

In the previous example we have focused on cost as the main driver and therefore used cable sized to support the expected load current. As a consequence the potential efficiency gain that could have been realized by using larger cables was not observed.

If we use the same cabling for both systems, then losses across the installation will reduce. A revised costing based on using the same AC Cabling for both the 960V and 415V distribution is provided:

Under this scenario when comparing the distribution network losses across the cabling, operating at 554/960V in comparison to 240/415V will result in a reduction in distribution losses of more than 5 times.

Efficiency gains with the UPS system which operate with reduced on-state losses and reduced internal reticulation losses will improve by approx 2% in comparison to a standard 415V unit.

	415V	960V	Saving
Main 11kV to 415 or 960V			
UPS Input Switchboard Cost	\$120,550	\$50,210	\$70,340
UPS Output Switchboard Cost	\$77,591	\$32,941	\$44,650
Cabling Costs	\$386,000	\$386,000	\$0
Total per System	\$584,141	\$469,151	\$114,990
Site Cost	\$1,752,450	\$1,407,453	\$344,997



Other Issues

Generator Supply – 960V Generator Supply can be achieved using a standard 415V alternator coupled with a step up transformer.

Air Conditioning Systems – These systems can operate on a separate 415V supply.

Summary

The application of higher voltage 3 wire reticulation can provide real benefits to the Data Centre, including:

- Reduced Copper Cost through the elimination of the neutral conductor and reduction in cable sizes with the associated savings in tray cost and installation labour.
- Increased utilization of standard LV components due to improved power densities.
- Elimination of balanced triplen harmonics generated by the IT load.
- Provision of a dedicated, clean MEN for the critical IT load.
- Improved operating efficiency of UPS equipment due to higher operating voltage and reduced currents.

With these factors in mind, we ask you consider the use of higher voltage reticulation when considering the design of a new large Data Centre.

THYCON

THYCON INDUSTRIAL PTY LTD
20 AUDREY AVE COBURG
3058 VIC AUSTRALIA
PH 61 3 9319 9000
FAX 61 3 9319 9001
ABN 17 068 011 049
EMAIL info@thycon.com.au
WEB www.thycon.com.au
24-HOUR SERVICE 1800 670 700

