

# **IMPEDANCE, SHORT CIRCUIT CURRENTS, AND VOLTAGE DISTORTION**

## **General**

<p>This application note addresses the significance of the output impedance of a transformer to short circuit currents and voltage harmonic development on</p>	<p>the applied source.  A quality transformer is made with copper coils wrapped around steel laminate. The coils characteristics</p>	<p>include resistance (R) and inductive reactance (X). The impedance (Z) is equal to the vector sum of resistance and inductive reactance.</p>
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## **Impedance**

<p>Impedance is the total current limiting factor (<math>i=e/z</math>). For transformers it is more convenient to rate the impedance as a</p>	<p>percentage than use its absolute value. Typical impedance is between 2% and 9%. At very low values of impedance (below 3%) a</p>	<p>correlation to efficiency can be established but there is no direct relationship because the resistance varies.</p>
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## **Fault Current**

<p>The purpose of investigating the impedance is the relationship to the transformer's short circuit current (Isc) and the associated circuit breaker fault clearing capacity. According to the NEC, a circuit breaker's rating must be at least 120% of it's full rated current.</p> <p>In the following example, the circuit breaker ampacity is 1000amps (833 x 120%) with a minimum asymmetrical interrupt current (AIC) capacity of 16,666 amps. Had the output impedance been 3%, the AIC would be 27,757 amps; requiring a more</p>	<p>expensive circuit breaker but rendering a much more efficient system. Therefore, a high output impedance transformer requires a lower AIC circuit breaker, however, the compromise contributes to voltage distortion. The lower cost of the circuit breaker is minor in comparison to the cost to correct the voltage distortion.</p>	<p>SAMPLE with: KVA Rating = 300 Input Voltage = 208 Vac Z = 5%</p> <p>Full load current = <math>\frac{300 \text{ Kva} * 1000}{208 \sqrt{3}}</math> = 833 Amps</p> <p>Isc = Short Circuit Current</p> <p>Isc = <math>\frac{\text{Full load current}}{\text{Impedance (Z)}}</math></p> <p>Isc = <math>\frac{833}{.05}</math></p> <p>Isc = 16,666 Amps</p>
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## **Voltage Distortion**

<p>An economical balance must be obtained when considering the impedance. Lowering the impedance minimizes the voltage waveform distortion, typically lowering the K-rating and increasing the fault current. This is not a concern below 150 KVA,</p>	<p>however, above 150 KVA, an abnormally low impedance becomes costly and difficult to coordinate the protection devices. A good compromise is to incorporate K-rated transformers with an impedance of 3 to 4% and operate the transformer at less</p>	<p>than full capacity. This approach assists in achieving operation within specified limits defined by IEEE 519, Maximum Harmonic Current Distortion in % of Load Current (Table 10.3).</p>
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Maximum Harmonic Current Distortion in % of IL Individual Harmonic Order (Odd Harmonics)						
$I_{sc} / I_L$	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even Harmonics are limited to 25% of the odd harmonic limits. TDD refers to Total Demand Distortion and is based on the average maximum demand current at the fundamental frequency, taken at the PCC.

\* All power generation equipment is limited to these values of current distortion regardless of  $I_{sc} / I_L$ .

$I_{sc}$  = Maximum short circuit current at the PCC  
 $I_L$  = Maximum demand load current (fundamental) at the PCC  
h = Harmonic order

**Table 10.3**

The electrical distribution contains harmonic currents, with the 5th and 7th harmonic being predominant. They cause additional heating and produce a voltage distortion. The voltage distortion produced is related to the impedance ( $e = iz$ ). In order to minimize the effects it is important to keep the impedance of the transformer low. IEEE 519 defines the acceptable Total Demand Distortion (TDD) for an individual harmonic order which is based on  $I_{sc}/I_L$ . ( $I_L$ = actual load current)

Example:

Case A  
 $I_{sc}$  = 16,666 Amps @ Z=5%  
 $I_L$  = 833 Amps 100%  
 $I_{sc}/I_L$  = 20

Case B  
 $I_{sc}$  = 27,575 Amps @ Z=3%  
 $I_L$  = 833 Amps 100%  
 $I_{sc}/I_L$  = 33

Case C  
 $I_{sc}$  = 27,575 Amps @ Z=3%  
 $I_L$  = 540 Amps 65%  
 $I_{sc}/I_L$  = 51

From table 10.3

Maximum current harmonic distortion for individual harmonic orders less than 11.

Case A = 4%  
Case B = 7%  
Case C = 10%

These cases demonstrate the need to keep the impedance low and refrain from full load current operation to minimize the harmonic current effects. K-rated transformers must be used in applications that involve harmonics to eliminate overheating. A premium K-rated transformer, at or below 500 KVA, should have no more than 4% impedance and an efficiency of 98% or better.

## Summary

Controlled Power Company manufactures the *Ultra-K*, a K-rated transformer with these conditions in mind. The output impedance is between 3% and 4%

with K-factors of K-4, K-7, K-13, and K-20. It is a multi-shielded isolation transformer, the only one in the industry with a pre-wired high frequency filter and TVSS. It

is designed for high harmonic current loads such as induction motors, welders, and mainframe computer networks.



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