PQSoft Case Study

Transformer Derating

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Miscellaneous2	Distortion		
References			

Abstract:

A principal effect of harmonic distortion is to increase losses and heating in almost every component in the electric power system. While contributing almost no useful work, harmonic components of voltage and current increase the RMS value of voltages and currents. Interaction of harmonic quantities and resistive loss mechanisms in power system components generates excess heat.

Power transformers are also affected by harmonic distortion. Distortion of transformer load current is the most significant impact, leading to higher than normal temperatures at "hot spots" within the windings.

This case presents an evaluation of transformer derating due to harmonic current.

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RELATED STANDARDS

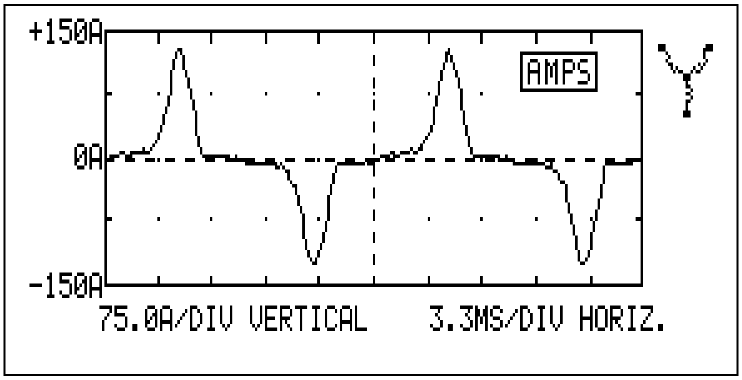
ANSI/IEEE Standard C57.110
UL Standards 1561 & 1562

GLOSSARY AND ACRONYMS

ASD	Adjustable-Speed Drive
CF	Crest Factor
DPF	Displacement Power Factor
PF	Power Factor
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
TPF	True Power Factor

PROBLEM STATEMENT

120 Volt, 75 kVA Transformer supplying computer workstations was running very hot at an office building. A check of the load current that the transformer was supplying showed that the amperage level was below the transformer rating. A spectrum analyzer was used to record the following waveform (Figure 1).



PHASE A CURRENT SPECTRUM 1:02:55 PM
Fundamental amps: 38.9 A rms
Fundamental freq: 60.0 Hz

HARM	PCT	PHASE	HARM	PCT	PHASE
FUND	100.0%	-5°	2nd	0.3%	-44°
3rd	65.8%	-22°	4th	0.5%	-38°
5th	43.6%	-41°	6th	0.5%	-20°
7th	20.3%	-64°	8th	0.5%	-5°
9th	7.0%	-93°	10th	0.2%	-3°
11th	0.6%	78°	12th		
13th	2.6%	-2°	14th	0.1%	-124°
15th	3.0%	-32°	16th	0.1%	-102°
17th	1.8%	-75°	18th		
19th	0.9%	164°	20th		
21st	1.0%	78°	22nd		
23rd	1.1%	129°	24th		
25th	0.6%	-67°	26th		

Figure 1 - Load Current Waveform and Spectrum

TRANSFORMER DERATING

A principal effect of harmonic distortion is to increase losses and heating in almost every component in the electric power system. While contributing almost no useful work, harmonic components of voltage and current increase the RMS value of voltages and currents. Interaction of harmonic quantities and resistive loss mechanisms in power system components generates excess heat. Some losses are actually sensitive to frequency, so that the power loss per ampere of harmonic current is actually greater than that for fundamental frequency currents.

Power transformers are also affected by harmonic distortion. Distortion of transformer load current is the most significant impact, leading to higher than normal temperatures at "hot spots" within the windings. If harmonic distortion of the load current is high, transformers must be derated to account for the increased heating effect of the distorted current. Guidelines for transformer derating are detailed in ANSI/IEEE Standard C57.110.

K-Factor Definition

K-Factor is defined in UL Standards 1561 (low voltage) and 1562 (medium voltage) as:

$$K = \frac{\sum I_h^2 h^2}{\sum I_h^2} \quad [1]$$

where:

h .... harmonic number

I_h .... harmonic current (amps)

Transformer Derating Using C57.110

ANSI/IEEE Standard C57.110 applies to general-purpose transformers that are subjected to a load current with a total harmonic distortion greater than 5%. The object of the standard is to determine the value of nonlinear current which results in transformer heating equal to that produced when the transformers is supplying rated linear load. Transformer derating can be determined using:

$$\sqrt{\sum I_h^2} = \sqrt{\frac{1 + P_{EC-R}}{1 + KP_{EC-R}}} \quad [2]$$

where:

P_{EC-R} ....Eddy current loss at hot spot under rated conditions

Transformer derating depends upon the per-unit rated eddy current loss factor at the hot spot (PEC-R). This factor can be determined by:

1. Obtaining the factor from the transformer designer
2. Using transformer test data and the procedure in C57.110
3. Typical values based on transformer type and size

Table 1 - Typical Values of P_{EC-R}

Type	**MVA**	**kV**	**%P_{EC-R}**
Dry	≤ 1		3-8
	≥ 1.5	5 kV HV	12-120
	≤ 1.5	15 kV HV	9-15
Oil Filled	≤ 2.5	480 V LV*	1
	≥ 2.5, ≤ 5		1-5
	> 5		9-15

Reference: "Adjustable-Speed Drive and Power Rectifier Harmonics. Their effects on Power System Components", D.E. Rice, IEEE No. PCIC-84-52 /

*Applies to any transformer with LV sheet type winding

Table 2 summarizes the calculations required to determine the transformer derating and K-Factor for the load waveform illustrated in Figure 1.

Table 2 - Transformer Derating Calculations

h	I_h	I_h (pu)	I_h^2	$I_h^2h^2$
1	100.0	1.000	1.0000	1.000
3	65.8	0.658	0.4330	3.897
5	43.6	0.436	0.1901	4.752
7	20.3	0.203	0.0412	2.019
9	7.0	0.070	0.0049	0.397
11	0.6	0.006	0.0000	0.004
13	2.6	0.026	0.0007	0.114
15	3.0	0.030	0.0009	0.203
17	1.8	0.018	0.0003	0.094
19	0.9	0.009	0.0001	0.029
21	1.0	0.010	0.0001	0.044
23	1.1	0.011	0.0001	0.064
25	0.6	0.006	0.0000	0.023
			1.6714	12.640

The K-Factor for the illustrated waveform is determined to be

$$K = \frac{\sum I_h{}^2 h^2}{\sum I_h{}^2} = \frac{12.640}{1671} = 7.56$$

and the transformer derating value is

$$I_{max(pu)} = \sqrt{\frac{1+P_{EC-R}}{1+KP_{EC-R}}} = \sqrt{\frac{1+0.08}{1+7.56(0.08)}} = 0.82\,\text{pu}$$

Note: P_{EC-R} assumed to be 8% for this case

Effect of P_{EC-R}

The impact of P_{EC-R} on transformer capability is summarized in Figure 2. As can be seen from the figure, as the eddy current loss factor increases the load current that can be supplied is reduced.

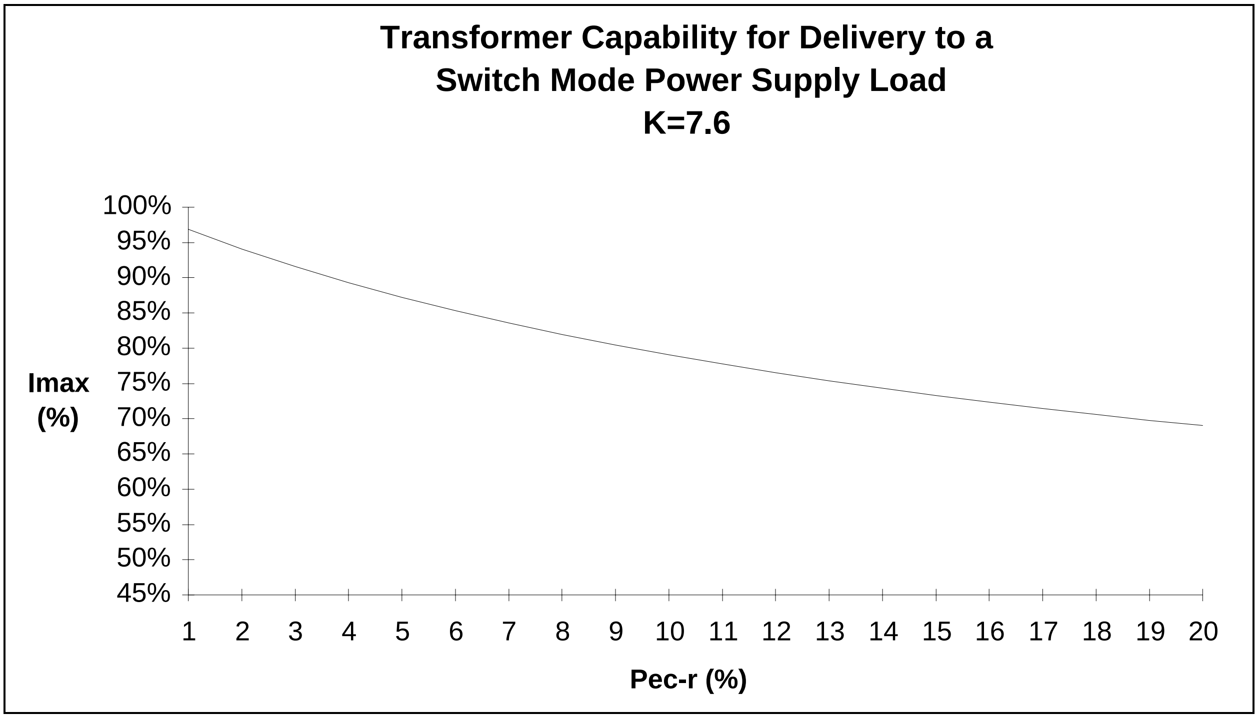


Figure 2 - Transformer Capability vs. P_{EC-R}

SUMMARY

The K-Factor for the load current illustrated in Figure 1 was determined to be 7.56 and the transformer derating value was found to be 82% of it's rated load current.

This means that the customer has several options when purchasing a transformer to supply this load:

- A 75kVA transformer with a K-13 rating (next standard size chosen)
- A K-1 transformers with a 91.5kVA (75/0.82) rating

REFERENCES

Reference: "Adjustable-Speed Drive and Power Rectifier Harmonics. Their effects on Power System Components", D. E. Rice, IEEE No. PCIC-84-52.

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