Effects of Harmonic Distortion I

Harmonic currents produced by nonlinear loads are injected back into the supply systems. These currents can interact adversely with a wide range of power system equipment, most notably capacitors, transformers, and motors, causing additional losses, overheating, and overloading. These harmonic currents can also cause interference with telecommunication lines and errors in power metering.

4.8.1 Impact on Capacitors

A capacitor bank experiences high voltage distortion during resonance. The current flowing in the capacitor bank is also significantly large and rich in a monotonic harmonic.

Figure 4.29 shows a current waveform of a capacitor bank in resonance with the system at the 11th harmonic. The harmonic current shows up distinctly, resulting in a waveform that is essentially the 11th harmonic riding on top of the fundamental frequency. This current waveform typically indicates that the system is in resonance and a capacitor bank is involved. In such a resonance condition, the rms current is typically higher than the capacitor rms current rating.

IEEE Standard for Shunt Power Capacitors (IEEE Standard 18- 1992) specifies the following continuous capacitor ratings:

- 135 percent of nameplate kvar
- 110 percent of rated rms voltage (including harmonics but excluding transients)
- 180 percent of rated rms current (including fundamental and harmonic current)
- 120 percent of peak voltage (including harmonics)

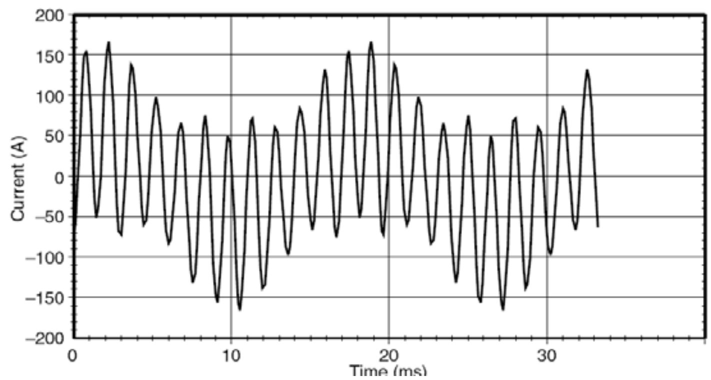

Figure 4.29 Typical capacitor current from a system in 11th-harmonic resonance.

4.8.2 Impact on Transformers

Transformers are designed to deliver the required power to the connected loads with minimum losses at fundamental frequency. Harmonic distortion of the current, in particular, as well as of the voltage will contribute significantly to additional heating.

To design a transformer to accommodate higher frequencies, designers make different design choices such as using continuously transposed cable instead of solid conductor and putting in more cooling ducts. As a general rule, a transformer in which the current distortion exceeds 5 percent is a candidate for derating for harmonics.

There are three effects that result in increased transformer heating when the load current includes harmonic components:

RMS Current

If the transformer is sized only for the kVA requirements of the load, harmonic currents may result in the transformer rms current being higher than its capacity. The increased total rms current results in increased conductor losses.

Eddy Current Losses

These are induced currents in a transformer caused by the magnetic fluxes. These induced currents flow in the windings, in the core, and in other conducting bodies subjected to the magnetic field of the transformer and cause additional heating. This component of the transformer losses increases with the square of the frequency of the current causing the eddy currents. Therefore, this becomes a very important component of transformer losses for harmonic heating.

Core losses

The increase in core losses in the presence of harmonics will be dependent on the effect of the harmonics on the applied voltage and the design of the transformer core. Increasing the voltage distortion may increase the eddy currents in the core laminations. The net impact that this will have depends on the thickness of the core laminations and the quality of the core steel.

Guidelines for transformer derating are detailed in ANSI/IEEE Standard C57.110-1998, *Recommended Practice for Establishing Transformer Capability When Supplying Nonsinusoidal Load Currents.* The common *K* factor used in the power quality field for transformer derating is also included in Table 4.1. The analysis represented in Table 4.1 can be summarized as follows.

The load loss *P*LL can be considered to have two components: *I*2*R* loss and eddy current loss *P*EC:

$$P_{LL} = I^2 R + P_{EC} \; W \qquad \text{------------------ (4.18)}$$

The I_2R loss is directly proportional to the rms value of the current. However, the eddy current is proportional to the square of the current and frequency, which is defined by

$$P_{EC} = K_{EC} \times I^2 \times h^2 \qquad \text{-------------------- (4.19)}$$

Where K_{EC} is the proportionality constant. The per-unit full-load loss under harmonic current conditions is given by

$$P_{LL} = \sum I_h^2 + \left(\sum I_h^2 \times h^2\right) \times P_{EC-R} \qquad \text{--------------------- (4.20)}$$

Where P_{EC} _ R is the eddy current loss factor under rated conditions. The K factor commonly found in power quality literature concerning transformer derating can be defined solely in terms of the harmonic currents as follows:

Type	MVA	Voltage	P_{EC-R}, %
Dry	≤	---	3-8
	≤1.5	5 kV HV	12-20
	≤1.5	15 kV HV	9-15
Oil-filled	≤2.5	480V LV	1
	2.5-5	480V LV	1-5
	>5	480V LV	9-15

TABLE 4.1 Typical Values of P_{EC} _ R

$$K = \frac{\sum \left(I_h^2 \times h^2\right)}{\sum I_h^2} \qquad \text{------------------- (4.21)}$$

Then, in terms of the K factor, the rms of the distorted current is derived to be

$$\sqrt{\sum I_h^2} = \sqrt{\frac{1+P_{EC-R}}{1+K \cdot P_{EC-R}}}\,(pu) \qquad \text{----------------- (4.22)}$$

Where PEC _ R = eddy current loss factor

h =harmonic number

I_h =harmonic current

Thus, the transformer derating can be estimated by knowing the per unit eddy current loss factor. This factor can be determined by

1. Obtaining the factor from the transformer designer

2. Using transformer test data and the procedure in ANSI/IEEE Standard C57.110

3. Typical values based on transformer type and size

4.8.3 Impact on Motors

Motors can be significantly impacted by the harmonic voltage distortion. Harmonic voltage distortion at the motor terminals is translated into harmonic fluxes within the motor. Harmonic fluxes do not contribute significantly to motor torque, but rotate at a frequency different than the rotor synchronous frequency, basically inducing high-frequency currents in the rotor. The effect on motors is similar to that of negative-sequence currents at fundamental frequency: The additional fluxes do little more than induce additional losses. Decreased efficiency along with heating, vibration, and high-pitched noises are indicators of harmonic voltage distortion.

At harmonic frequencies, motors can usually be represented by the blocked rotor reactance connected across the line. The lower-order harmonic voltage components, for which the magnitudes are larger and the apparent motor impedance lower, are usually the most important for motors.

There is usually no need to derate motors if the voltage distortion remains within IEEE Standard 519-1992 limits of 5 percent THD and 3 percent for any individual harmonic. Excessive heating problems begin when the voltage distortion reaches 8 to 10 percent and higher. Such distortion should be corrected for long motor life. Motors appear to be in parallel with the power system impedance with respect to the harmonic current flow and generally shift the system resonance higher by causing the net inductance to decrease.

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