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The effects of harmonic distortions on transformers

By

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Abstract:

The use of electric power is a natural part of life. It is used everywhere for living, work and traveling, at any residence, commercial building , industry and so on , to supply the loads.

The new technique devices , as loads , are used to achieve better performance , to be able to control and to transfer more power over the power system and to reduce the power consumption of the loads . These new techniques consist of non-linear components that are used to control the load current.

Non-linear components in power system distort the current waveform and can affect the voltage waveform. These distortions can create a variety of power quality problems.

The voltage and the current distortion cause additional losses in power system components and in linear loads. Transformers are major components in power systems. Increase in harmonic distortion component of the transformer will result in additional heating losses, shorter insulation lifetime, higher temperature and insulation stress, reduced power factor, lower productivity, efficiency, capacity and lack of system performance of the plant.

The paper overviews and assessments the effects of real measured harmonic distortions on different low voltage level transformers supplying different types of non-linear loads.

Keywords:

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1. Introduction:

It's the task of the electric utility to supply its customers with sinusoidal voltage of fairly constant magnitude and frequency .The generators (supply side) produce the electric power generator a very close approximation to sinusoidal waveform.
However there are loads and devices on the system which have nonlinear characteristics and result in power quality disturbances.
Some power quality (PQ) problems are supplied to customers' load through the supply side system, and some are caused by the customers themselves.
Many problems original with one customer and travel through the distribution system, and even the transmission system, to impact other end – users. Some manufactures are now equipping their products with filters and short –term storage devices so that they will be immune to many PQ problems. Local solutions to PQ problems tend to be the most cost – effective.
There are many measures and indices of power quality. Some of the more common indices are the following:
-Total harmonic distortion (THD): the ratio of the rms value of the sum of the individual harmonic amplitudes to the rms value of the fundamental frequency.
-Harmonic loss factor (F_{HL}): the sum of the squares of the individual harmonic currents and their harmonic orders divided by the sum of the squares of the individual harmonic currents.

2. Losses in power distribution systems:

There are two major sources of losses in power distribution systems
These are the transformers and power lines. In addition, there are two major types of losses that occur in these component .These losses are often referred to as core losses and copper, or I^2R losses. Core losses in transformers account for the majority of losses at low power levels .As load increases, the copper losses become more significant, until they are approximately equal to the core losses at peak load.

3. ***Effects of harmonic in networks:***

The main effects of harmonic distortion in networks are the following:
Destruction of capacitors in consumers' installation due to the amplification of the normal operating current, by resonance.
Increasingly , overheating of transformers and neutral conductor caused by harmonic currents particularly of the 3 rd order , fires may result from excessive 3^{rd} order harmonic currents because these harmonic currents add in the neutral whereas the fundamental frequency current cancel each other out so that neutral conductors in 3- phase circuits

have not in the past needed to be separately protected against overload
The flow of harmonic currents in power systems, caused by non-linear loads of customer may affect telephone communication.

-Low power factor associated with non-linear loads are responsible for substantial increase in the currents flowing in supply systems and consumers installations, and then in the cost of losses
Consumer installations and distribution systems are sometimes forced to derate their transformers loading because of the heating effects of harmonic currents. Transformer manufactures recommend derating by 10% when a transformer supplies more than 30% of its normal capacity to non linear loads

4. ***Effect of power system harmonics on transformers:***

Power system harmonics are divided to voltage and current harmonics, as shown in Fig (1). The effect of each one is considered in the following

Power system harmonics

Voltage harmonics (V_h)
{ $\emptyset_h \alpha V_h$ }
{ $\emptyset_h \alpha 1/h$ }

Current harmonics (I_h)
-P_{dc} losses
- winding eddy losses
-stray losses

Fig. (1) *Classification of power system harmonics*

Effect of voltage harmonics:
The flux magnitude is proportional to the voltage harmonic and inversely proportional to the harmonic order (h). The most power systems have $THD_v < 5\%$ and V_h rarely exceeding a level of 2-3 % .This is determined by the low internal impedance of most supply systems carrying harmonics. Therefore neglecting the effect of harmonic voltage and considering the no load losses caused by the fundamental voltage component will only give rise to an insignificant error.

Effect of current harmonics:
In most power systems, current harmonics are of more significance. The harmonic current components cause additional losses in the windings and other structural parts. Table (1) summarizes the effect of current harmonics on transformers.

Table (1):*Effect of current harmonics on transformers*

Type of losses	**cause**	**effect**
P_{dc} losses (losses due to dc resistance)	Increased I_{rms}	P_{dc} losses increase with I^2_{rms}
Winding eddy losses (P_{EC})	-generated by the electromagnetic flux -varied with I^2_{rms} and h^2 $Pec = Pec - R \sum_{h=1}^{hmax} h^2 (I h/IR)^2$ h=1, 2…	-excessive winding losses -abnormal temperature rise
Stray losses (P_{sL})	-stray flux, which introduces losses in iron parts. -varied with I^2_{rms} and $h^{0.8}$ $P_{osl} = P_{osl-R} \sum h^{0.8} (I_h/I_R)^2$	-elevate the temperature of the structural parts -increase the oil temperature and thus the hot spot temperature

Where:
P_{EC} is the winding eddy loss due to non-sinusoidal current
P_{EC-R} is the winding eddy loss under rated conditions
P_{osl} is the stray losses in the structural parts due to non sinusoidal current
P_{osl-R} is the stray losses in the structural parts under rated conditions

5. Harmonic loss factor (F_{HL}) [1]

The eddy current losses produced by a harmonic current (P_{EC}) can be predicted based on the eddy current losses at rated current (P_{EC-R}) and fundamental frequency, according to the following equation:

$$Pec = Pec - R \sum_{h=1}^{hmax} h^2 (I h/IR)^2$$

The harmonic loss factor is

$$F_{HL} = \sum_{h=1}^{hmax} h^2 I_h^2 / \sum_{h=1}^{hmax} I_h^2$$

The winding loss (hot spot specific power loss) (P_w) can be calculated as:
P_w (pu) = I^2(pu)[1+ P_{EC-R}(pu) F_{HL}]

The F_{HL} can be used to predict the increased eddy losses .this is very significant when calculating the temperature rise .which is the limiting factor in transformer loading.
The F_{HL} is a key indicator for the current harmonic impact on the winding eddy losses, under rated sinusoidal current:
I (pu)=1, F_{HL}=1, P_w(pu)=1+P_{EC-R} (pu)

Evaluation of transformer loading capacity [1]
The recommended method in [1] for dry type transformers is based on the condition that the PU value of the non-sinusoidal current will cause the same hot spot losses as the rated sinusoidal current
This can be expresses as:

$$I_{max}\,(Pu) = \sqrt{\frac{P_{W-R}\,(Pu)}{1+F_{HL}{*}P_{EC}(pu)}} = \sqrt{\frac{1+P_{EC}(Pu)}{1+F_{HL}{*}P_{EC}(pu)}}$$

This assumes that the normal life of the unit will be maintained
The calculation for liquid filled transformers is similar to the dry type except the other stray losses must be included.

6. ***Power survey results:***
19 power surveys are carried out at low voltage side of different rating of distribution transformers. All these case studies are carried for variety industrial firms. The electrical parameters measure by energy analyzers. The measurement period is one day and an hour interval.
By using the measured I_{THD}% and losses for transformers, The F_{HL} and loading capacity, for each transformer, are calculated. The results classified as following:

- Group (1): maximum measured load between 67% to 85% and the recommended loading capacity between 70% to 85%
- Group (2): maximum measured load between 27% to 54% and all transformers in these group can be more loaded
- Group (3): maximum measured load more than 90% and the recommended loading capacity is closed to the maximum measured load, except one case needs to derate transformer loading.

Table (2): *summarizes resulted for industrial firm*
Group (1)

Case study	Rated KVA for transformer	Max measured load %	Max measured THD %	F_{HL}	Recommended loading capacity %
1	2000	54	34	7	85
2	1000	27	84	21.5	65
3	2000	53	32	6	87
4	2000	38	21	3	95
5	1000	30	70	17	69
6	1500	36	39	8	83
7	1500	47	44	9	81
8	1000	41	54	13	78
9	2000	44	19	2.5	96

Group (2)

Case study	Rated KVA for transformer	Max measured load %	Max measured THD %	F_{HL}	Recommended loading capacity %
1	1500	98	15	2	97
2	1000	91	8	1.5	98
3	1500	94	38	8	83
4	1500	96	8	1.5	98

Group (3)

Case study	Rated KVA for transformer	Max measured load %	Max measured THD %	F_{HL}	Recommended loading capacity %
1	1500	73	49	11	77.5
2	1000	67	55	12	75
3	500	67	68	16	70
4	1000	76	51	11.5	76
5	1500	85	34	7	85
6	1500	78	36	7.5	84

7. Conclusions:

. The losses that occur in distribution system are large enough to make efforts to reduce them worthwhile .core losses in transformer which account for the majority of

distribution losses at low power, can be reduced by improved core materials and by reducing harmonics copper losses which become more important at higher power levels can be reduced by a number of mea including increased use of copper distribution lines, shunt compensation, demand side management and by reducing harmonics.
The paper presents many results of measurements for the transformer derating factors when they are subject to different loading % and I_{THD}%

References:

[1] IEEE std. C57-110-1998, *recommended practice for establishing transformer capacity when supplying non sinusoidal load currents.*
[2] *Evaluation of power system harmonic effects on transformers* .Asaad A.Elmoudi TKK Dissertations 24 Espoo 2006.
[3] *Losses in electric power systems*, Purdue university Purdue university Purdue-e-pubs ECE technical reports Electrical and computer engineering -1992.

Nomenclatures:

$\mathbf{F_{HL}}$	Harmonic loss factor
THD	Total harmonic distortion
$\mathbf{P_{dc}}$	losses due to dc resistance
$\mathbf{P_{EC}}$	winding eddy loss due to non-sinusoidal current
$\mathbf{P_{EC-R}}$	winding eddy loss under rated conditions
$\mathbf{P_{w}}$	winding loss
$\mathbf{P_{osl}}$	stray losses in the structural parts due to non sinusoidal current
$\mathbf{P_{osl-R}}$	stray losses in the structural parts under rated conditions