Dry-Type Transformers & Energy Saving for the Future

Hammond Power Solutions Inc.

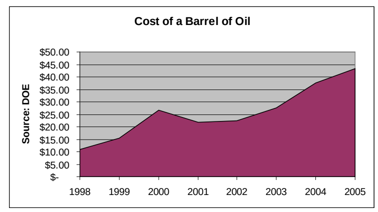
Introduction

On August 8th Congress and President Bush signed the Energy Policy Act of 2005; it changed the definition of efficiency for dry-type distribution transformers.

Of course like any new law, many interpretations developed causing some confusion and trepidation in the transformer industry on who was responsible for the implementation of this new standard in transformer efficiency.

The objective of this legislation is to save large amounts of energy or for some, save on the escalating cost of energy while at the same time saving the environment.

This all started in approximately 1992 when the United States Department of Energy began studies on energy saving in transformers. A study by one of the DOE collaborators, the E-source Group in 1995, estimated that most of the transformers measured were only loaded at an average of 35% and since most dry-type transformer efficiencies were designed to be loaded at 100% of the name-plate capacity, they were not very efficient at the 35% level. The estimated potential for losses in this study was from 60 to 80 billion kWh, and with proper design the annual savings could be up to $1 billion per year.



Some further studies confirmed this and the latest one by the CADMUS Group in 1999 established that for low voltage only, the average loading was 16% with estimated annual losses of 17 billion kWh and potential savings of 350 million kWh with proper designs.

	E-Source-1995	**ORNL-1997**	**CADMUS - 1999**
Annual Losses	60-80 billion kWh (based on discussions with researchers from ORNL)	80 billion kWh	17 billion kWh (Energy saving for low voltage only)
Annual Saving Potential	1 billion US$ per year	330-400 million kWh	350 million kWh
Load Factor	35%	35%	16%

Table 1 Opportunities/Savings Potential of Dry-Type Transformers
Sources : Barnes et al. 1997; E-Source 1995; Korn et al. 1999

TP1

In 1996, the National Electrical Manufacturing Association (NEMA) published an efficiency standard for dry-type distribution transformers called TP1 for use by industry manufacturers.

In an effort to harmonize the North American standard, CSA in Canada established its C802/2000 which became the C802.2 and in 2004 in the spirit of the Kyoto protocol, the Canadian government passed a law which came in to effect on January 01, 2005.

On that date all 60 Hz dry-type distribution transformers installed in Canada must comply and meet the C802.2 efficiency standards.

For the USA, effective January 1st 2007, all 600 volts class distribution transformers manufactured and installed will have to meet the NEMA TP1-2002 energy efficiency standards in the range of:

- 1ph, 15-333 kVA, low voltage
- 1ph, 15-833 kVA, medium Voltage, 20-150 kV BIL
- 3ph, 15-1000 kVA, low voltage
- 3ph, 15 to 2500 kVA, medium voltage, 20-150 kV BIL

As expected and in view of the complexity of the ruling, some are mainly looking for a possible loop hole for immediate first cost saving, neglecting the major energy cost saving for the end user.

Electrical Systems

All of the studies and rulings on transformer efficiency are of course for our North American 60Hz electrical systems. In addition, these efficiencies are calculated for the traditional resistive loads referred to as 'linear loads'.

When we say 35% average loading, it is expected the loads will sometimes be higher or lower. In fact the best efficiency of a dry-type transformer should not be at precisely 35% but in a window of 16% to 65%.

Non-Linear

Motors became drives; ballasts became electronic devices and then began a proliferation of switching power supplies with the massive growth in the computer industry. Because of this, in a modern building one can expect to see up to 90% of the loads to be 'Non-Linear'.

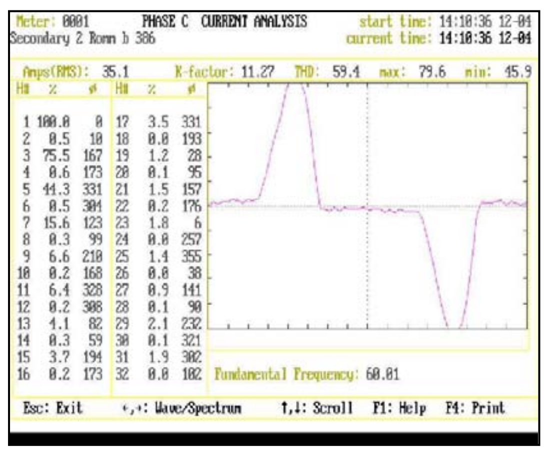
The use of non-linear loads is not new in the electrical world. They were introduced many years ago with the introduction of DC drives and rectifiers. The DC drive was the only way to regulate the speed of a motor and some equipment in the transport industry. This required the rectifier to produce DC voltage.

The Office Building

The computer industry needed a better, more reliable and less susceptible method to control voltage fluctuations at a lower cost. This would produce DC voltage for computers.

The introduction of Switching Power Supplies (Three Pulses) changed the industry. These devices use the 60Hz current sine wave, due to their design to produce DC current, they will distort the current and because of the Ohms law, distort the voltage. In other words, "it generates Harmonics on the AC system or THD (Total Harmonic Distortions)".

A large proportion of the harmonics produced by this single-phase application (switching power supply), are 'triplet' harmonics (zero sequence harmonics). This is natural for single-phase switching power supplies.



Typical Office Panel

These frequencies (triplet) are not cancelled on the neutral at the design phase shift of 120° on the 60Hz North American electrical grid (3θ). One of the consequences is that the neutral wire becomes overloaded and this could start a fire on the fourth wire.

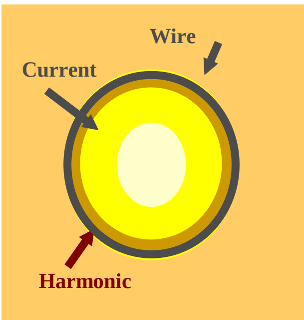
To control motors and save energy for ventilation and heating, we started using AC motors with a 6-pulse, 3-phase Converter Bridge and the "Pulse Width Modulation" technology. This produced substantial harmonics. But since it is a 3 phase application, it does not produce triplet harmonics. It does however produce (5th, 7th, 11th, 13th, etc.) harmonics on the primary side which distorts the voltage and produces losses on the 60Hz systems. These voltage distortions could damage some electric motors and/or resonate with power factor correction capacitors or detuned filters.

One important consequence of the current distortion is the voltage wave distortion. Current is load related, but voltage feeds every load in the system thus affecting the overall efficiency of the loads in the system.

Energy Saving for the Future

One important factor for the choice of utilizing "non-linear load technologies" is the energy savings. The fact that it uses energy at only a fraction of the full sine wave will save energy. As an example a good retrofit to an AC motor is to install a drive. It gives more flexibility to processing but it also reclaims some energy.

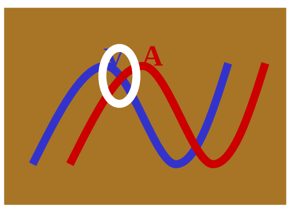
Now with electronic ballasts for lighting, computers, UPS, PLCs and for HVAC applications (electronic control, fan pump drives) just to name a few, it is clear that this is the direction of the future.



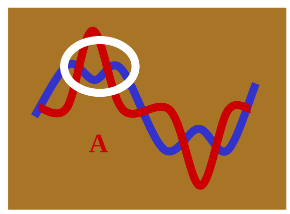
Because of their designs, the problem with non-linear loads is that they feed harmonics back into the system, and these are multiples of 60Hz, therefore are at higher frequencies.

As frequencies increase, and electricity travels through the wires, the current will travel more and more on the outside layers of the cables thus increasing the losses. These energy losses will cause more heat and there is an energy cost in some cases to circulate this heat.

You will also have degradation on the efficiency of the system due to the poor Total Power Factor. This appears in the form of distortion power factor created by the distortions of the current and voltage sine wave.



DISPLACEMENT Pf



DISTORTION Pf

Installation

These factors should influence the installation protocol. If you look at a typical office panel connected to the secondary of a transformer, you will notice the biggest quantity of an order of harmonic is the 3^{rd} (74%). The longer the cable is on the secondary, the greater the losses.

Since this current will be travelling on the outer layer of the cable it would be good practice to parallel the cable where the code permits. Using this same approach you would have to install the transformer as close as possible to the loads.

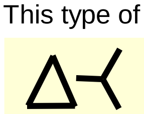
If you phase shift the transformers by 30°, you will cancel the 5^{th}, 7^{th} … harmonic components and in turn will correct the total power factor. It will also cancel the harmonic components at very low impedance, minimizing the losses created by the frequency currents.

TP1, Modern Loads and Dry-Type Transformers

With all this in mind, let's now have a look into how a transformer should be designed to maximize the energy savings. We will not consider a Delta-Delta connection since there is no need for this type of connection in distribution. It could also be dangerous if the system is not well grounded (floating) and could cause electrocution.

Delta Wye connection

This type of connection is the most common in a distribution circuit. In Canada the most popular primary voltage is 600 and the most common secondary voltage is 208/120. You could connect three phase loads and also single phase loads on the same secondary.



Delta Wye connections can be designed for standard, NEMA TP1 energy saving for linear loads, K-Factor for non-linear loads and K-Factor NEMA TP1 energy saving for non-linear loads. It can also be optimized to reduce the losses by up to 25% more than the standard, which means it would retain its NEMA TP1 rating even under a non-linear load profile of K-Factor 20.

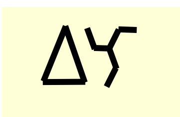
The best performance however would be to keep NEMA TP1 efficiency from 35% to 65% under linear or non-linear loads.

The biggest challenge with these designs is the fact that under a single phase non-linear load application the biggest harmonic component is the triplet (3^{rd}, 9^{th} etc.) and those triplets will circulate in the delta side of the transformer with the full impedance of the design. To achieve better performance under those conditions is difficult and the cost of the material increases immensely, however the payback is still very short compared to the traditional model (non NEMA TP1).

The best efficiencies therefore can be achieved by using the Delta Y connection for three phase loads, three wires.

<u>What to do for single phase non-linear loads (e.g. computer)?</u>

Delta Zigzag connection



It's been around now for 15 years and was mainly used for Power Quality applications and phase shifting.

The secondary connections have one half of the phase connected to the other half of the second phase and so on. This means that if you divide 120°, which is the angle between the phases by two, you get 60° phase shift. This is the right angle shift to cancel the triplets and is done at very low impedance, typically 0.95. This will minimize the losses and therefore save energy.

If you compare the Delta Wye connection to the Delta Zigzag connection under single phase office loads, you get up to <u>20% less losses</u> which makes this design very appropriate.

Energy Efficiencies at a TP1 level are easily achieved when utilizing this kind of design. If you optimize this type of transformer you can meet those efficiencies under all loading conditions of an office building from 35% to 65% of the rated nameplate capacity.

Furthermore, this design is very well suited for phase shifting as they are built with minimum cost difference to make a 0° or a 30° phase shift with the primary. You can also easily phase shift two loads for further cancellation of harmonics on the primary side at low impedance. This will improve your "Total Power Factor".

Conclusion

By applying energy saving approaches like the ones we have just discussed, you will save energy that will payback your initial equipment cost quickly and at the same time will promote Power Quality by minimizing the voltage distortions.

When the new 'Energy Efficiency' standard for dry-type distribution transformers became law on January 01, 2007, which promotes energy saving transformer design concepts, the first industry reaction will be to find <u>loop holes</u> to reduce the first purchase cost, neglecting the obvious continuous savings to the customer.

Not only are the energy cost savings significant today, but as the cost of electrical energy continues to rise, it is not hard to realize significant increased savings in the very near future.