T9

Effect of direct current DC on transformers

a brand of Schneider Electric

Merlin Gerin

Electrical networks and direct current

Certain electrical circuits, such as transport networks powered by direct current, are a known source of direct current magnetic fields in transformers.
With the increased use of electronic power equipment in power transmission networks and in industry, there is a constant rise in the number of possible sources of magnetization with direct current components.
The article cited as a reference (''Harmonics from SVC Transformer Saturation with Direct Current Offset'') describes these phenomena.

Because of developments in magnetic materials and the industrial production of magnetic circuits, the non-saturated magnetizing inductance is very large and the DC resistance very small in transformers of recent design. The no-load currents in these recent transformers are generally very low and the effect of a direct current component is even more pronounced.

In certain user electrical network configurations, the very large reduction in the magnetizing impedance of the transformer can give rise to electrical resonances with capacitive components in the network (cables, capacitors, etc.). These resonances can be sufficient to cause damage to the transformer.

Phenomena engendered by the presence of direct current

The principal consequences of the presence of a direct current component injected into the winding of a transformer are the following:

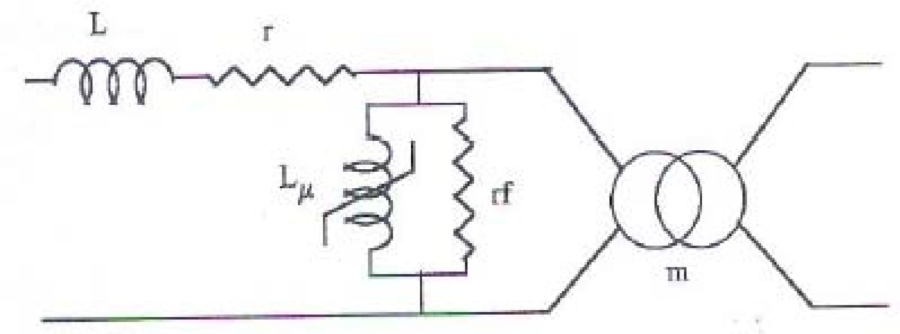
1. Saturation of the magnetically-soft material of the magnetic circuit
2. A very considerable reduction in the magnetizing impedance of the transformer
3. Internal electrical resonance in the transformer windings
4. Increased noise level
5. Increased no-load current I_0 and losses P_0

1 - Magnetic circuit saturation

If a transformer is supplied by network alternating current and is also subjected to injected direct current in a winding, the result is 2 different magnetic flux circulations in the magnetic circuit of the transformer, with a DC flux superimposed on the AC flux.
This means that the hysteresis cycle $\beta = \beta(H)$ of the magnetic material is shifted and increased with the DC bias.
The DC component is a very sensitive parameter and a small DC bias can lead to the complete saturation of the magnetic core of the transformer with the generation of harmonics (distortion of signals).
The order of magnitude of the DC current necessary to saturate the transformer is the same as that of the transformer no-load current i.e. a few % of the nominal current.

2 - Very large reduction in the magnetizing impedance of the transformer

When the magnetic circuit of the transformer is saturated, the relative permeability μr = μr(β) of its constituent material decreases very significantly (by a factor of 1000 to 10000) with the increase in the level of saturation of the circuit.
The result of this saturation is that the magnetizing impedance of the transformer (and the relative permeability of the magnetic material) also decreases very significantly.
In the following equivalent diagram of the transformer, the magnetizing inductance Lμ decreases very strongly on saturation of the magnetic circuit:



Equivalent diagram of transformer, per phase, seen from the HT/primary side:

L : *leakage inductance of transformer*
r : *on-load transformer losses, modelled by a resistance*
Lμ : *magnetizing inductance of transformer*
rf : *no-load losses of transformer, modelled by a resistance*
m : *transformation ratio*

3 - Internal resonance in the transformer windings

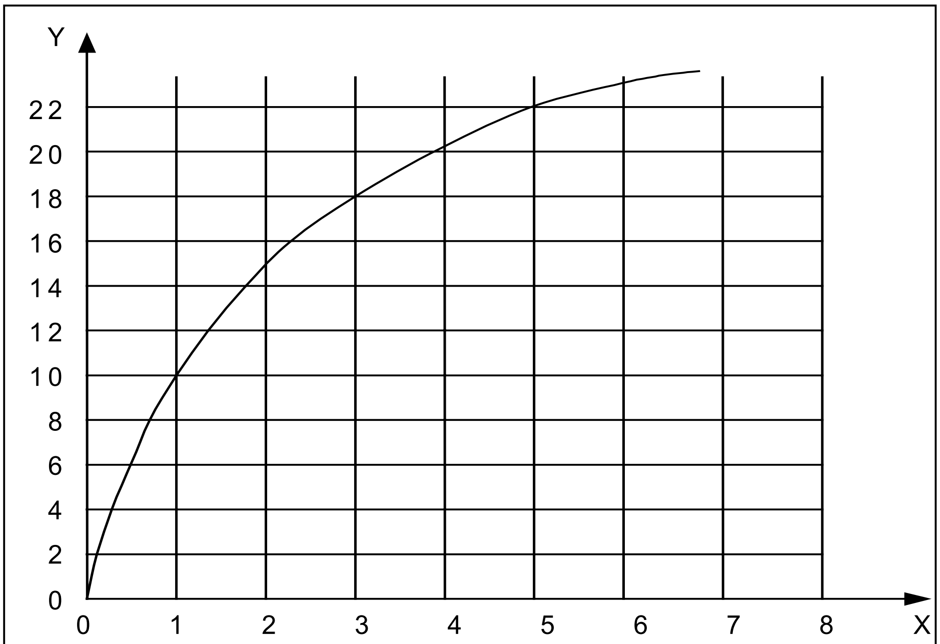
Because of the rapid reduction in its magnetizing impedance, the transformer may enter into resonance with capacitive components in the electrical network such as MV and LV cables, capacitor banks, etc.

This resonance between the transformer and capacitive components in the electrical network is possible if, in a given network configuration, the harmonic frequencies which are present correspond to at least one of the resonant frequencies of the transformer.
If this is the case, local overvoltages and overcurrents are generated within the transformer winding.
These internal resonances eventually degenerate into dielectric incidents leading to transformer damage.

4 - Increased noise level

Complete saturation of the magnetic circuit occurs in practice with DC components equal to 3 times the no-load current of the transformer. Since the no-load current approximates to only 1% of the nominal current of the transformer, the result is that a DC component of some 3% of the nominal current will completely saturate the magnetic circuit. A small direct current component (order of magnitude 5 A to 100 A depending on the size of the magnetic circuit of the transformer) will therefore completely saturate the circuit.
This saturation engenders a very significant rise in the noise level of the equipment in service.

The document ''*IEC 60076-10-1 / User Guide / Determination of Transformer Noise Levels* gives a curve of the increase in the noise level of a transformer, expressed in dB(A), as a function of the multiple of the no-load current I_0.
This curve, established for power transformers, is as follows:



X axis – Direct current component as a multiple of AC no-load value

Y axis - Increase in noise level dB(A)

Increase in noise level with direct current in windings

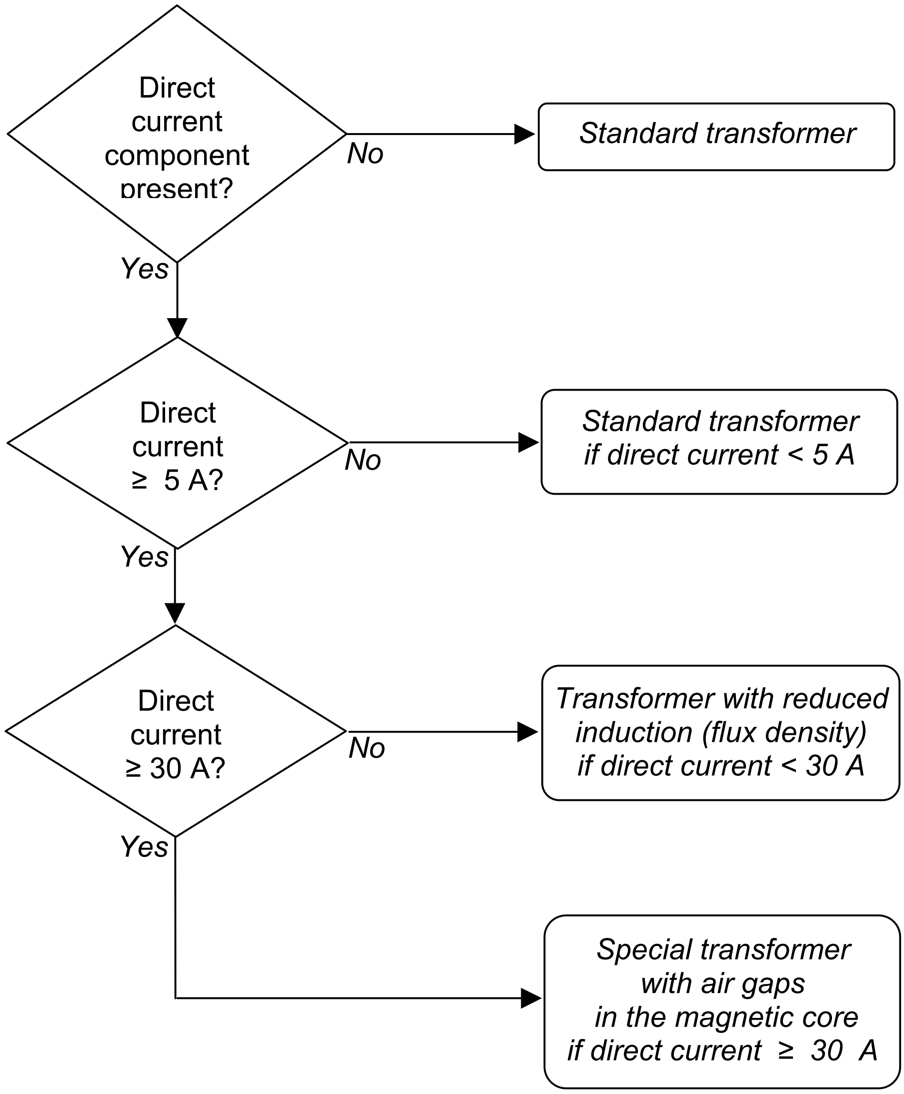
5 – Increase in no-load currents (I_0) and losses (P_0)

The presence of a direct current component saturates the magnetically-soft materials (iron-silicon sheets) in the magnetic circuit. The level of magnetic induction in the circuit therefore rises significantly and tends towards the saturation induction of the material.
The magnetic performance of the magnetic material deteriorates and, as a result, the no-load currents (I_0) and no-load losses (P_0) increase strongly.

Corrective measures: applicable case-by-case

Depending on the direct current levels measured on the site, corrective measures must be taken as early as the design stage of the transformer.

Example: In the case of a 2500 kVA, 22000V - 433V Trihal transformer installed on a given site, the potential corrective solutions are illustrated in the following diagram:



Conclusion

The effect of injecting direct current into the winding of a transformer is broadly the same as the effect of switch-on i.e. a major asymmetrical inrush of start-up current occurs.
During the transient phase of transformer start-up, the starting current also has a DC component due to its asymmetrical shape and it is well known that electrical stresses can occur on the energized phase at this moment.
So it is essential to know the accurate DC level in order to adapt the transformer consequently.
The IEC 60076-11 standard gives moreover recommendations to adapt the design of the equipment in this case.

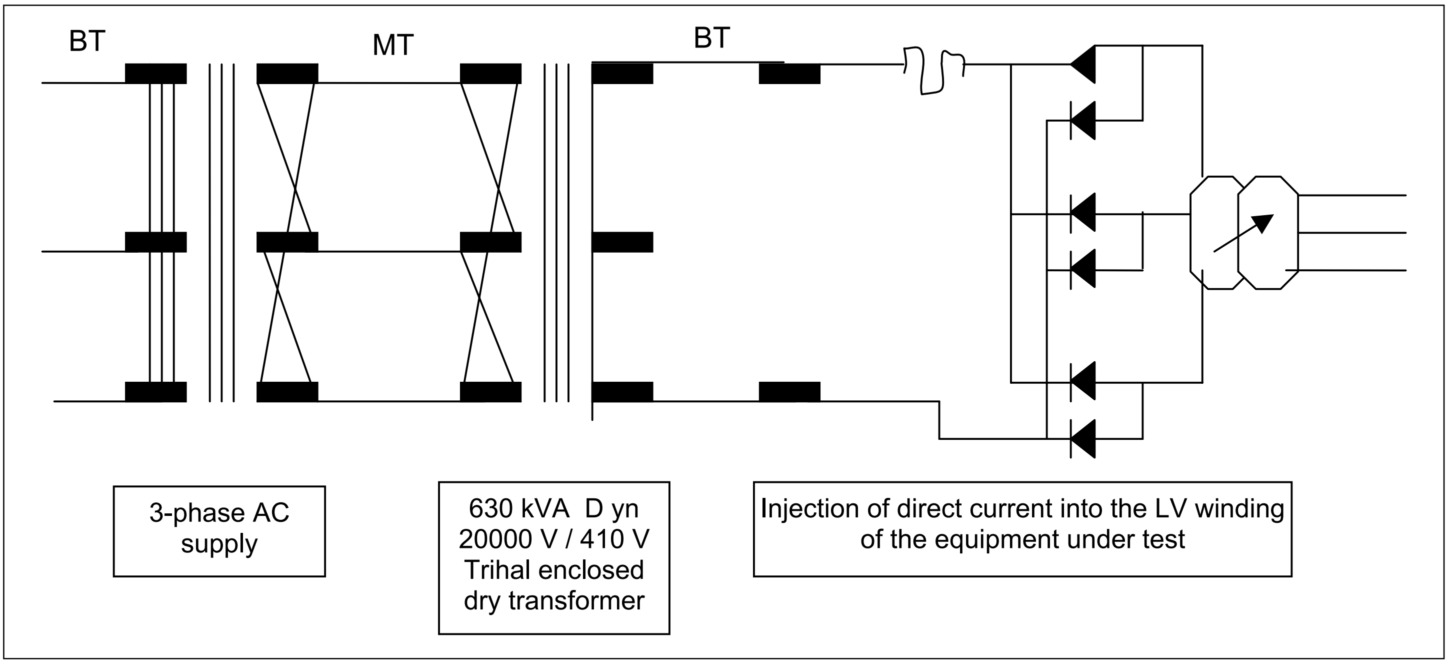
APPENDIX

Injection of a direct current component into the low tension winding

Test carried out on a cast resin Trihal transformer

Diagram of testing arrangement

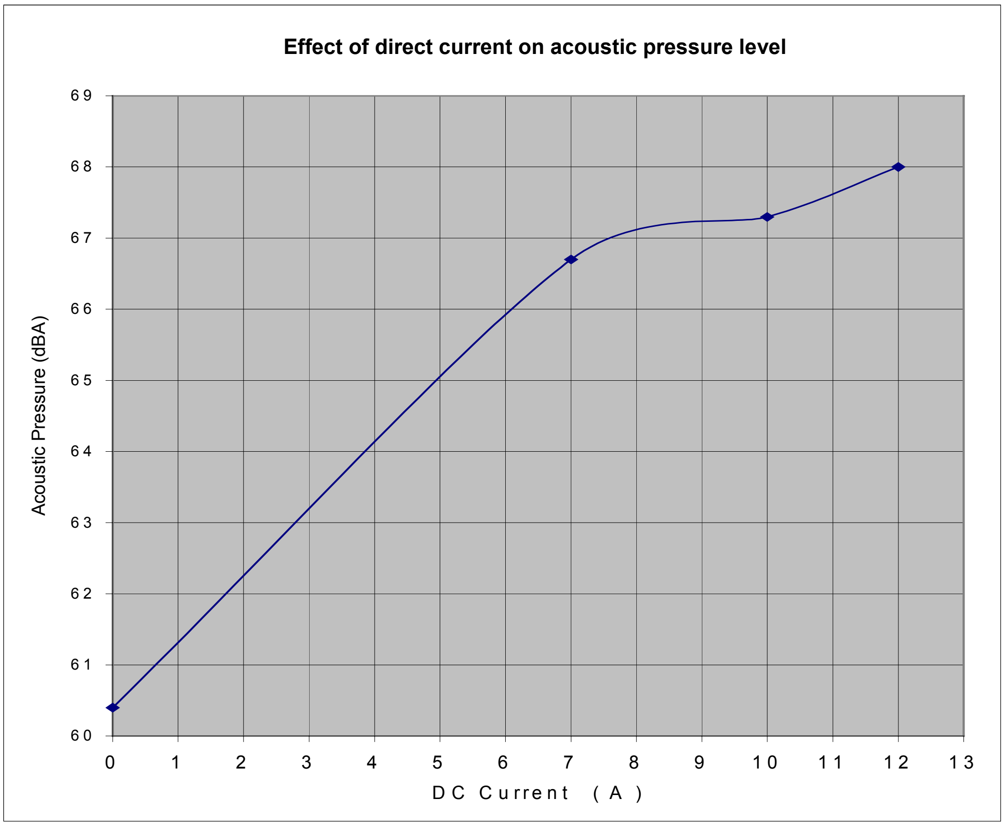
This test was carried out in the factory.
In the connection diagram below, the equipment under test is supplied with 3-phase current from an intermediate transformer on the MT side.
Using a variac and bridge rectifier, direct current is injected between phases a and c of the LV winding of the transformer under test.
Two filtering inductors decouple the alternating current and direct current circuits.



Test results

The following table and curve show the acoustic pressure level measured at 1 m from the transformer being tested, as a function of the injected direct current I_{dc} in the low tension winding.

I_{dc} (A)	Acoustic pressure at 1 m (dBA)
0	60.4
7	66.7
10	67.3
12	68.0



Conclusions of test

With this test arrangement, we observe an increase in the transformer noise level of more than 7 dB(A) for a direct current of 12 A injected into the LV side of the transformer.
As a comparison, the nominal AC current in the LV side of the transformer is 887 A and the measured no-load current (without DC injection) is 8.4 A at the nominal supply voltage.
Furthermore, the level of no-load current is multiplied by a factor of 2 approximately between the configurations with and without the injection of a direct current of 12 A into the LV side of the transformer.

After injecting a small direct current I_{dc} (equal to approximately 1.5 times the no-load current), the magnetic circuit of the transformer saturated, with a significant increase in noise level of 7 dB(A) and in the level of no-load current, which doubled in value.

Reference

- Harmonics from SVC Transformer Saturation with Direct Current Offset IEEE – Vol 9 N° 3 , July 1994 – BC Hydro - Canada