Effects of Magnetizing Inrush Current on Power Quality and Distributed Generation

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Abstract. When a power transformer is energized there is an important transient inrush of current that it is necessary in order to establish the magnetic field of the transformer. Some power transformers exhibit peak current demand up to eight or ten times the nominal value. In addition, during the first cicles high values of the homopolar components of current are also requested by the transformer. If the power transformer is placed in a substation that works as a common coupling point for distributed generation facilities some specific power quality problems can be found.

This paper analyzes the problem from a general point of view considering not only the theoretical approach but also the results obtained in a real case including two 180 *MVA* power transformer and a 120 *MW* distributed generation.

Keywords. Power Quality, distributed generation, protections, inrush current, homopolar components

1. Introduction

From a general point of view, the magnetizing of power transformer can be the origin of some power quality problems. First at all, it should be underlined that the transient of current that is required to establish the magnetic field of the transformer during the magnetization can not be considered a fault condition so it should not cause protective relays to operate. A basic approach to the problem can be done considering a coil surrounding a ferromagnetic material which is supplied from a sinusoidal voltage [1]. The steady-state flux can be computed as the integral of the supplied voltage $v(t)$,

$$\phi(t) = \frac{1}{N}\int v(t)dt = \frac{1}{N}\int \cos(\omega t)dt = \frac{1}{\omega N}\sin(\omega t) \quad (1)$$

Equation 1 highlights the fact that flux lags the voltage by 90 degrees.

Considering the coil as a linear inductance, the current will have exactly the same waveform as the flux, that is,

$$i(t) = \frac{1}{L}\int v(t)dt \quad (2)$$

However, it is well known that the ratio between the flux density ϕ and the magnetic field intensity H in a ferromagnetic material is linear while H is lower than a value that define the knee of the saturation curve. Transformers are designed to operate close the knee of the saturation curve of the core hysteresis loop when the machine is working under normal conditions. When a transformer is connected after a period out of service, the conditions of the analysis are different. Considering that the transformer is energized when the voltage is zero and there is not residual flux or in the worst case, the residual flux has a value that is the opposite to the theoretical means that the resulting flux will be up to twice its normal maximum value. In this case the magnetizing current will be many times the nominal value because the non-linear behavior of the transformer core. Figure 1 shows the current required to provide a given level of flux.

The duration and amplitude of the inrush current is a function of two sets of parameters [2], [3]. The first one considers parameters which belongs to the transformer. The second includes parameters from the power system. Among others, the following should be considered:

1) Nominal power of the transformer.
2) Material used to build the core of the transformer.
3) Residual flux just before the connection of the power transformer.
4) Short circuit power at the common coupling point.
5) Distance between the bus of the substation and the power transformer.

Points 1, 2 and 3 are specific from the transformer, while 4 and 5 are defined by the power system at which the power transformer is connected.

2. Power quality problems derived from Magnetizing Inrush Current

From a power quality point of view, the magnetizing inrush current can be considered as a distorted wave with two kind of disturbances [1], [2]:

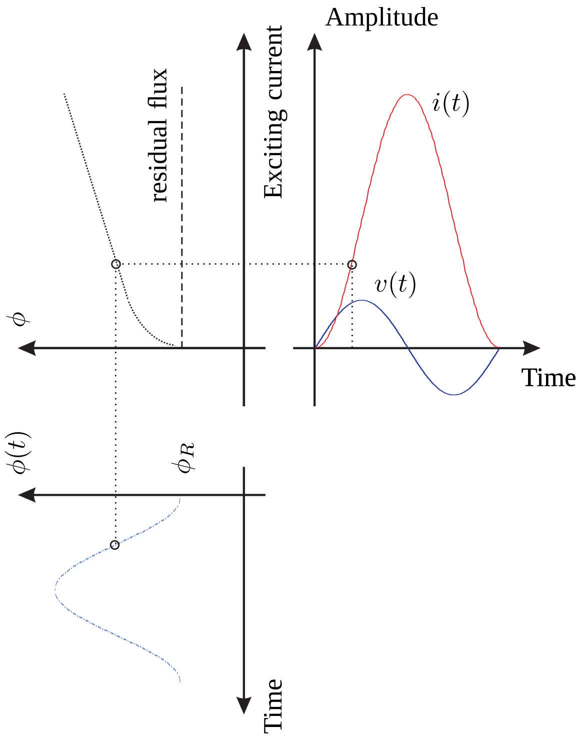

Figure 1. Electrical magnitudes involved in the inrush current of the power transformer magnetization.

- Unbalance
- Harmonics

A. Unbalance

Current unbalance can not be considered a disturbance. Asymmetrical loads produce unbalanced currents. In the same way, the magnetizing inrush current produces current unbalance during magnetization. This condition can be used in parallel with the second harmonic in order to know what it is happen during the connection of the transformer.

B. Harmonics

The current demanded by the transformer during the magnetization contains all orders of harmonics. However, only the second and third harmonics are relevant. The dc component can also be significant during the first cycles depending on the residual flux. The most significative harmonics are the following:

- **DC or offset component**. A dc component can be found almost always in the inrush current, with different values for each phase of the three-phase system. The offset is a function of the residual flux.
- **Second harmonic**. The second harmonic is present in all inrush current of all three phases. The value of the second harmonic is a function of the degree of saturation. Anderson [1] says that the minimum value for the magnitude of this harmonic component is about 20% of the excess magnetizing current.
- **Third harmonic**. Third harmonics in the inrush current can be found with the same magnitude that second harmonics. They are produced by saturation.
- **Higher harmonics**. Harmonics of high order are present with different values. Actually, they have small values so can be neglected.

3. Distributed generation

The protection of the generation units is more complex than the protection of static machines like transformers. In addition, protection experts suggest the necessity of disconnecting the generators when harmonics or current unbalance are upper than a threshold level. The main reason is that harmonic components produce an increment of the heat inside the machine. This heat can produce mechanical problems derived from the resistance of the materials used to build the generators. Ac generators are sensitive to harmonics and unbalance. Problems can be summarized as follows [3]:

Harmonics	In spite of the fact that there are different harmonic components in the inrush current, special attention has to be paid to the second harmonic. This frequency component is not present in fault currents so can be use in order to test if the fault condition is true or only a magnetizing condition.
Unbalance	This disturbance produce negative-phase-sequence components of current which induce a double-frequency in the surface of the rotor, the retaining rings, the slot wedges, and to a smaller degree, in the field winding. These induced currents can produce high temperatures in relatively short time.

4. Magnetizing inrush supression

When the magnetizing inrush current is high enough to produce power quality problems due to the trip of the relays that protect both the power transformer of the generators, there are several method that can be use in order to avoid these problems [4], [5], [6]. The basis idea is to desensitize the relay during the transformer magnetization. It can be done adding a time delay or observing the current harmonics. New techniques like artificial neural networks can help to discriminate between magnetization and fault conditions [7].

5. Test results

A. Real case

A real case including two 180 *MVA* power transformers and 120 *MW* distributed cogeneration has been analyzed.

Both the power transformers and the generators are connected to a 220 *kV* substation. Figure 2 shows the studied power system.

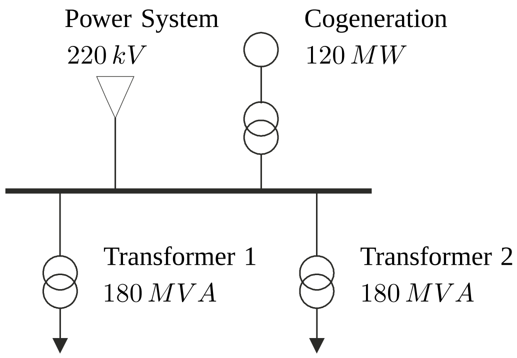

Figure 2. Power System under Test.

B. Results

The power system has been put to the test in order to measure the magnetizing inrush current.

Figure 3 shows the rms value of the voltage at 220 kV bus during the magnetization of the power transformer. The machine is magnetized without any connected load.

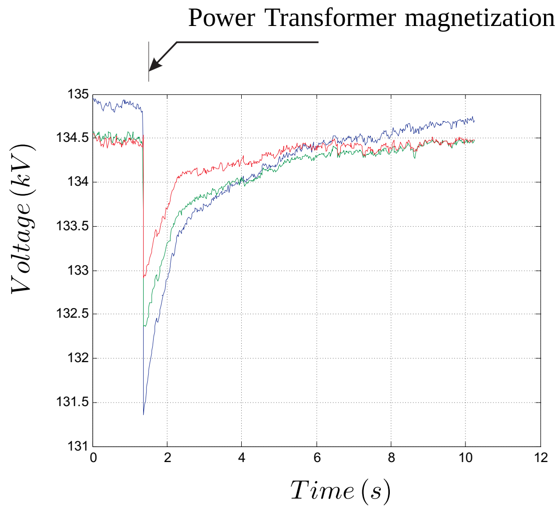

Figure 3. Voltage evolution at 220 kV bus during power transformer magnetization.

Figure 4 shows the rms value of the current demanded by the primary side of the transformer during the magnetization process in the same conditions that figure 3.

Figure 5 shows a current snapshot of the first cycles after the connection of the power transformer with the same conditions that figure 3.

Figure 6 shows the rms value of the homopolar component of the current demanded by the transformer during the magnetization. This component has to be supplied by the power system and the distributed generation.

Finally, figure 7 shows the second harmonic component of the current demanded by the transformer during the magnetization.

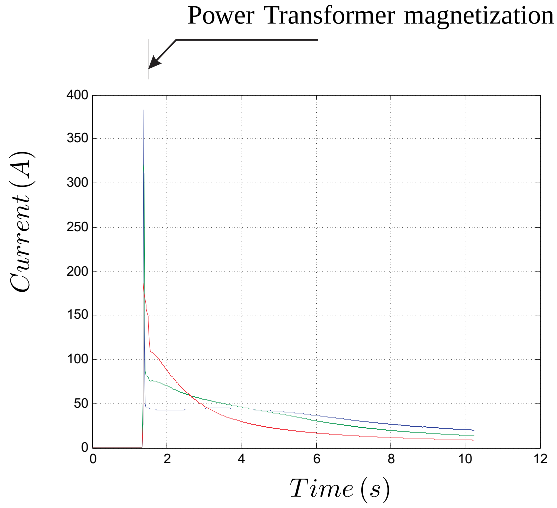

Figure 4. Current demanded by the power transformer number 2 during the magnetization (rms value).

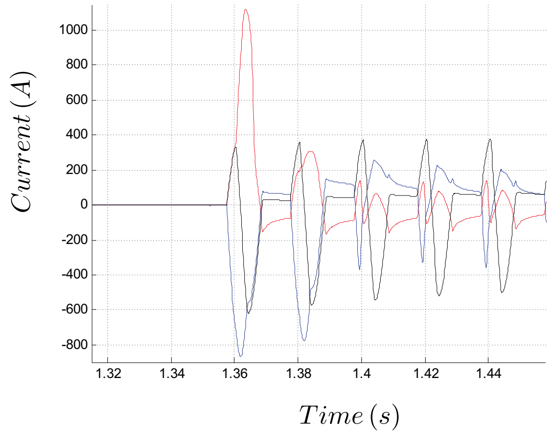

Figure 5. Current demanded by the power transformer number 2 during the magnetization (snapshot).

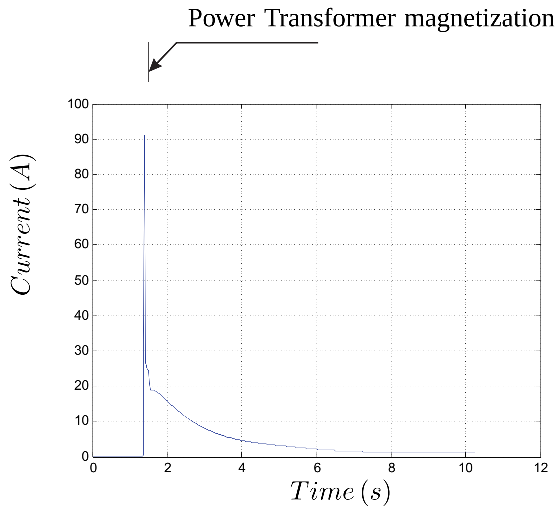

Figure 6. Homopolar current demanded by the power transformer number 2 during the magnetization (rms value).

From the point of view of the distributed generation, figure 8 shows the rms value of the current supplied by the distributed generation during the transformer mag-

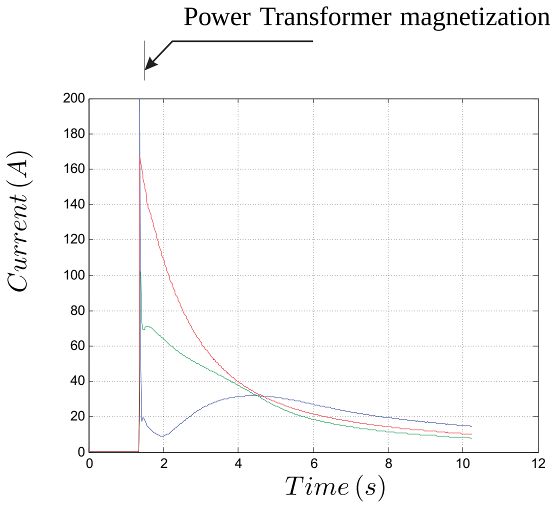

Figure 7. Second harmonic current demanded by the power transformer number 2 during the magnetization (rms value).

netization. Figure 9 shows the homopolar component of the current supplied by the cogeneration during the magnetizing process.

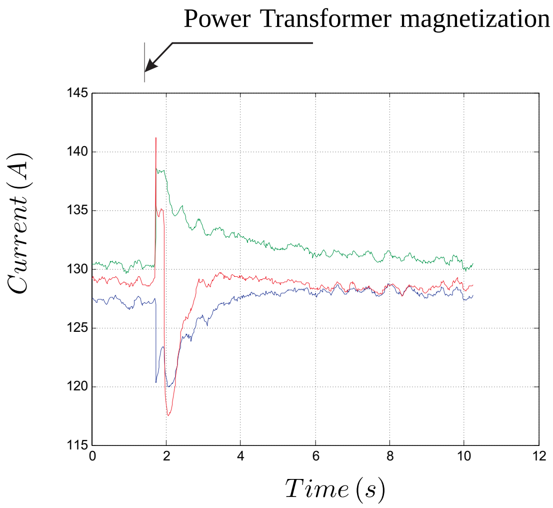

Figure 8. Current supplied by the cogeneration during the magnetization (rms value).

6. Conclusions

This research work highlights the necessity of limiting the magnetizing inrush current of power transformers, especially when they share bus with distributed generation. This problem is more important when the short circuit power at the common coupling point has reduced values. In order to avoid false trips produced by the transformer magnetization, a second condition can be add to the generation protection schemes.

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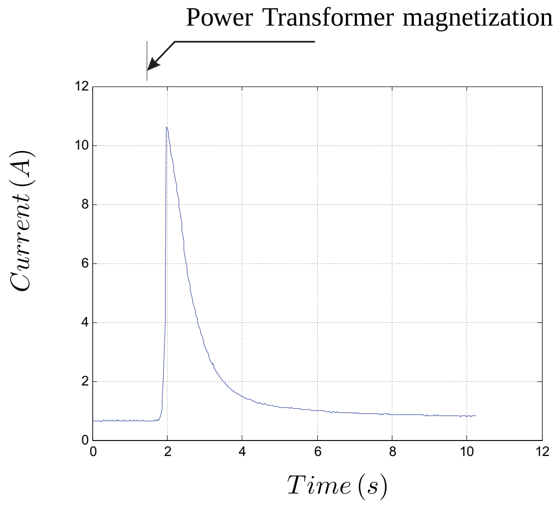

Figure 9. Homopolar current supplied by the cogeneration during the magnetization (rms value).

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