Case Study Of Sympathetic Interaction Between Transformers Caused By Inrush Transients

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Abstract—In power systems transients caused by energization of power transformers are one of the common problems. In power systems sympathetic inrush phenomenon is not uncommon when two transformers are connected in parallel. The transformer already connected to supply system can experience unexpected saturation during the inrush transient of an incoming transformer. Inrush conditions of a transformer produce false differential currents that could cause relay misoperation. In this paper sympathetic inrush phenomenon between transformers is analyzed. Saturable transformer and power system is modeled by STRI-SIMPOW simulation program. Simulation results are compared with test results that are obtained from SCOPEMETER 199-C (200MHz) energy analyzer.

Keywords: Inrush current, parallel transformers, sympathetic inrush

I. Introduction

POWER transformers are the most important and very expensive component in a power system. Avoiding damage to power transformers is very expensive. The operating conditions of transformer protection do not make the relaying task easy. Transformers are usually protected by means of a differential scheme. The transformer differential relay should be designed such that it does not misoperate during magnetizing inrush [1] and overexcitation conditions which fool differential relay operation.

II. Magnetic Inrush

The study of transformer excitation inrush phenomenon has spanned more than 50 years [5]. Magnetizing inrush occurs in a transformer whenever the polarity and magnitude of the residual flux do not agree with the polarity and magnitude of the ideal instantaneous value of steady-state flux. Although usually considered a result of energizing a transformer, the magnetizing inrush may be also caused by [2]:

a) occurrence of an external fault,
b) voltage recovery after clearing an external fault,
c) change of the character of a fault,
d) energizing of a transformer in parallel with a transformer that is already in service.

Since the magnetizing branch representing the core appears as a shunt element in the transformer equivalent circuit, the magnetizing current upsets the balance between the currents at the transformer terminals, and is therefore experienced by the differential relay as a false differential current.

A. Inrush Due To Switching-in

Initial magnetizing due to switching a transformer in is considered the most sever case of an inrush. When a transformer is de-energized, the magnetizing voltage is taken away, the magnetizing current goes to zero while the flux follows the hysteresis loop of the core. This results in certain remanent flux left in the core. When, afterwards, the transformer is re-energized by an alternating sinusoidal voltage, the flux becomes also sinusoidal but biased by the remanence. The residual flux may be as high as 80-90% of rated flux [3], and therefore, it may shift the flux-current trajectories far above the knee-point of the characteristic resulting in both large peak values and heavy distortions of the magnetizing current. It is shown in Fig.1.

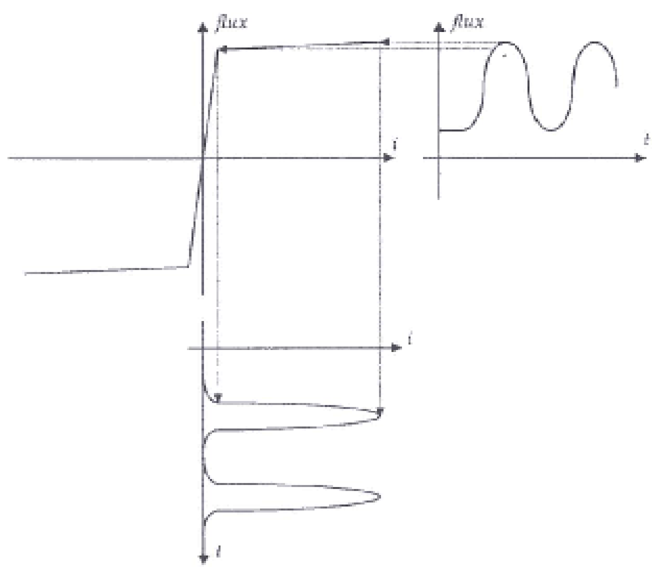

Fig.1 Illustration of the magnetizing inrush

Fig.2 shows a typical inrush current. The waveform displays a large and long lasting dc component, is rich in harmonics, assumes large peak values at the beginning, decays substantially after a few tenths of a second, but its full decay occurs only after several seconds.

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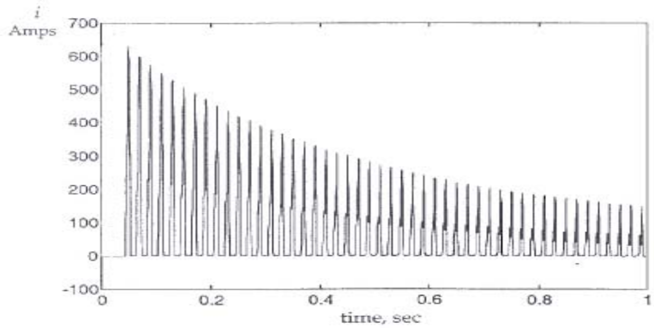

Fig.2 Typical inrush current

The slope, magnitude and duration of inrush current depend on several factors [3]:

a) size of a transformer,
b) impedance of the system from which a transformer is energized,
c) magnetic properties of the core material,
d) remanence in the core,
e) moment when a transformer is switched in,
f) way a transformer is switched in (inner, outer winding, type of switchgear).

B. *Sympathetic Inrush Due To Parallel Energization*

One aspect of this transient that has largely been ignored in the relevant literature is the effect of the inrush current on the transformers that are already in operation. The traditional method for calculating inrush current assumes that the transformer is being switched onto a system to which there are no other transformers connected. In practice, however, transformers are normally energized in parallel with other transformers that are already in operation.

In any system model that including a generator connected to a bus through a transmission line having a resistance R and an inductance L is shown in Fig.3. The transformer T_1 is energized, and the transformer T_2 is being energized by closing the breaker B. As the breaker B closes, an inrush current is established in the primary winding of the transformer T_2, and is supplied by the generator through the impedance of the transmission line. The inrush current has a dc component, which decays with a somewhat long time constant. This decaying dc component produces a voltage drop in the resistance of the transmission line. The dc voltage drop is of a polarity as shown in Fig.3 for an assumed positive dc component flowing in the direction shown. Since the generator output is purely ac, and cannot be affected by this voltage drop, it is clear that the voltage of bus A acquires a negative dc component. This results in a negative change in the flux linkages of the two transformer cores. As the transformer T_2 was assumed to have a saturating flux in the positive direction the effect of this flux change is to take T_2 out of saturation, and cause a possible saturation of T_1 in the negative direction. Consequently, the inrush current in T_2 decreases in time, and the inrush in T_1increases in the opposite direction up to dc components in the two inrush currents become equal to each other [4].

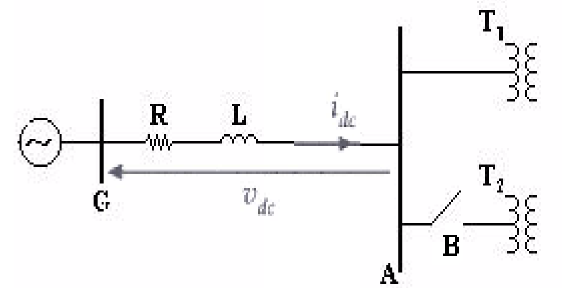

Fig.3 Connections leading to the sympathetic inrush

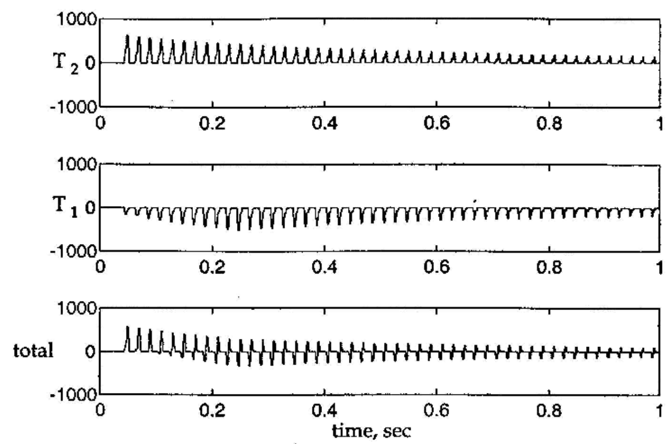

Fig.4 Typical sympathetic inrush currents

This phenomenon, which has been pointed out as one of the reasons for false operation of transformer differential relays and prolonged temporary harmonic overvoltages on power systems.

III. MEASUREMENTS

A. *Simulated System Results*

Electrical system simulated by software STRI SIMPOW. SIMPOW is a program that can make digital simulation and analysis of electrical power systems. It is developed by ABB and in 2004 transferred to STRI [6].

The system is composed of a 210 kV, 170 MVA generator and two 210/10.2 kV 170 MVA three phase saturable power transformers, a transmission line of 5 km in length. The power transformers have a delta connection in the primary windings and a star connection in the secondary windings. It is modeled using DSL (Dynamic Simulation Language) in STRI SIMPOW. Single line diagram of the system is shown in Fig.5.

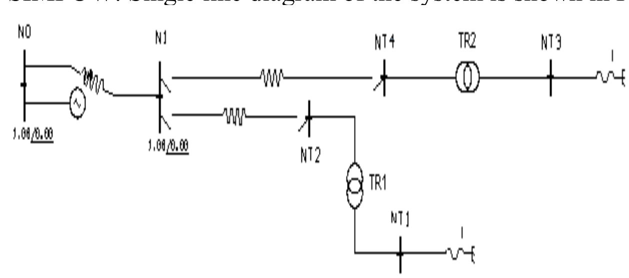

Fig.5 Single line diagram of the system

The transformer TR1 is energized at the instant 0.05 sec. by closing the breaker. As the breaker closes, an inrush current is established in the primary winding of the transformer then at the instant 0.5 sec the transformer TR2 is energized. Fig.6 and Fig.7 shows the waveforms of the transformer TR1 and the transformer TR2 phase currents.

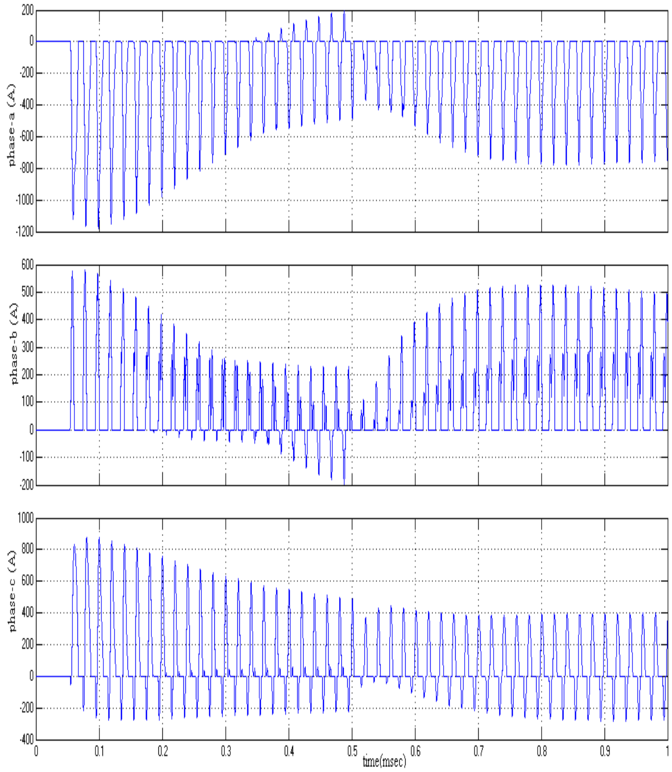

Fig.6 Phase currents of the transformer TR1

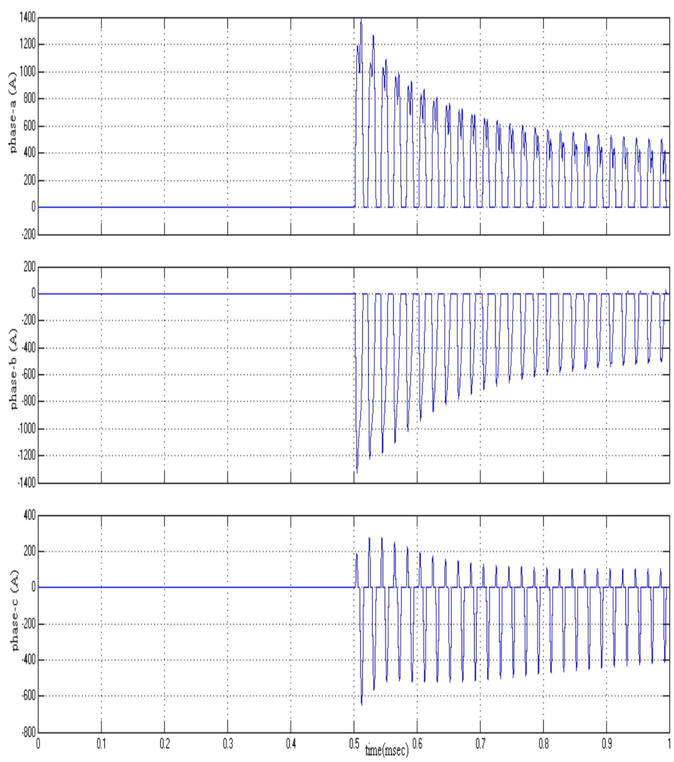

Fig.7 Phase currents of the transformer TR2

1) Harmonic Analysis

In this paper harmonic analysis of current waveforms are made using Discrete Time Fourier Transform (DTFT).

It was decided that for reasons of numerical accuracy, the sampling rate is 1000 samples/s or 20 samples for one 50 Hz period which more than adequately satisfies the Nyquists criterion. The data sets are obtained from simulated system by software SIMPOW. The data sets belong to simulated system are used for obtaining the second harmonic components of current signals. Measuring fundamental and second harmonics of differential current, an algorithm based on the one cycle Discrete Fourier Transform and an amplitude estimator which uses 20 samples in order to find the magnitudes of harmonics are used. Magnitudes of harmonic frequencies are obtained by the Discrete Fourier Transform, using a sliding window of one cycle.

The harmonic analysis shows high even harmonics in current. Even harmonics are the characteristic harmonics of transformer saturation and they are used to restrain the operation of the differential protection of the transformer during energizing. Even harmonics are not common in power systems and basically depict the asymmetry between the positive and negative half cycle of waveform.

Fig.8 and Fig.9 show the amplitude of the 2^{nd} harmonic of the transformers TR1 and TR2 phase-a current.

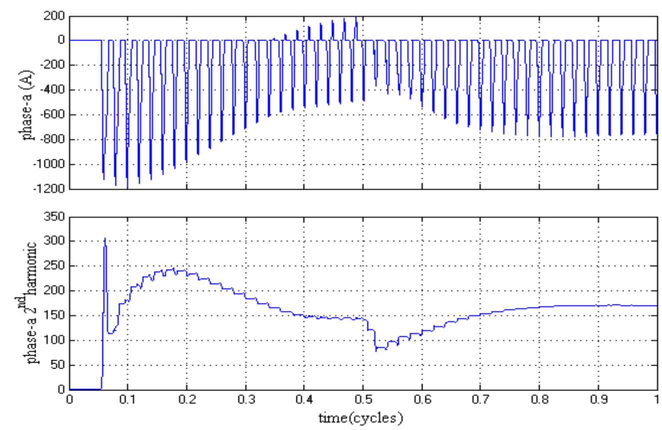

Fig.8 The transformer TR1 phase-a current and its 2^{nd} harmonic component

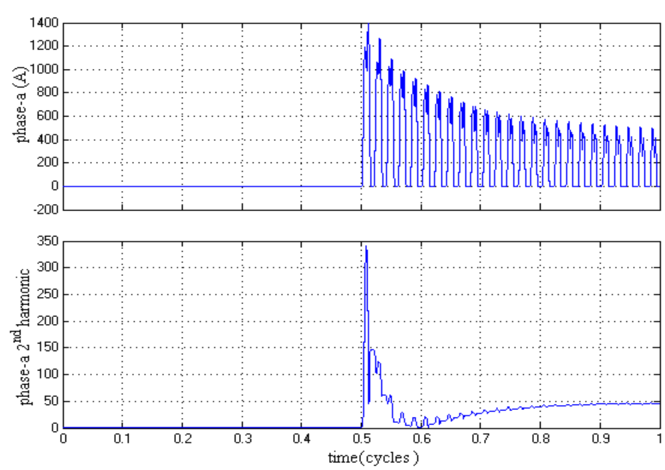

Fig.9 The transformer TR2 phase-a current and its 2^{nd} harmonic component

B. Real System Test Results

To test the system two three phase 1kVA, 240/120V transformer is used. The winding resistance, winding reactance, magnetizing resistance, magnetizing reactances are 1.06ohm, 1.21ohm, 1669ohm and 1462ohm, respectively.

The transformer TR1 is energized at the instant 0.57 sec. by closing the breaker. As the breaker closes, an inrush current is established in the primary winding of the transformer then at the instant 3.1 sec the transformer TR2 is energized. Fig.10 shows the waveforms of the transformer TR1 and the transformer TR2 phase-a currents.

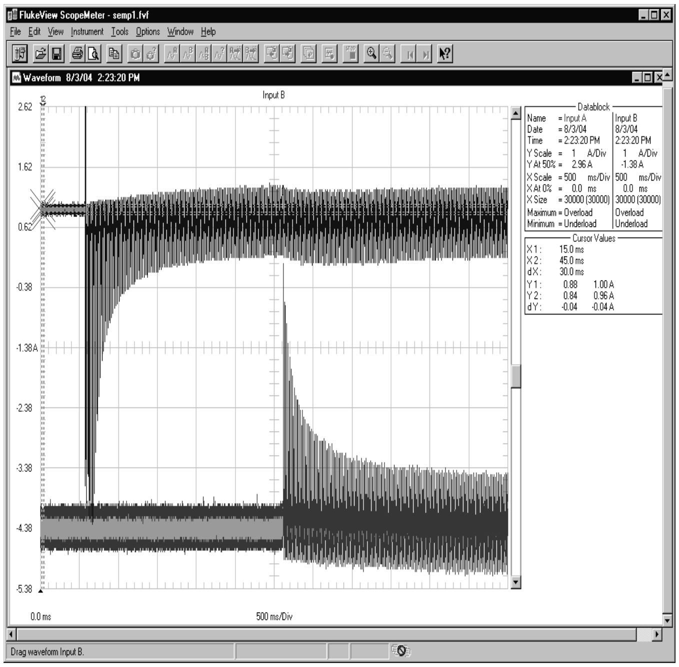

Fig.10 Phase-a currents of the transformers TR1 and TR2

1) Harmonic Analysis

In this paper harmonic analysis of current waveforms are made using Discrete Time Fourier Transform (DTFT).

It was decided that for reasons of numerical accuracy, the sampling rate is 1000 samples/s or 20 samples for one 50 Hz period which more than adequately satisfies the Nyquists criterion. The data sets are obtained from real test system by using SCOPEMETER 199-C.

Fig.11 shows the amplitude of the 2^{nd} harmonic of the transformers TR1 phase-a current.

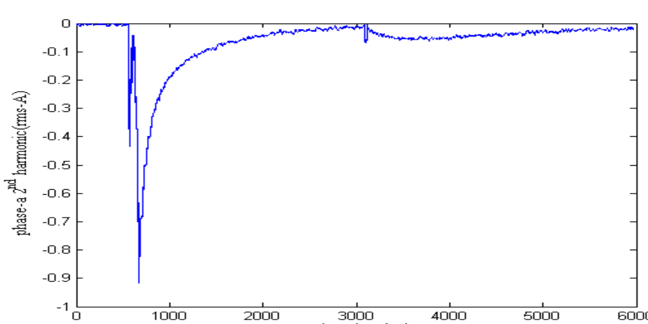

Fig.11 Phase-a current of the transformer TR1

Fig.12 shows the percentage of the 2^{nd} harmonic to fundamental of the transformers TR1 phase-a current. It is seen that when the transformer TR2 is energized the percentage harmonic is raises about 20%. The percentage of second harmonic to fundamental is depend on the moment of energizing, remenance flux, ect. So the percentage may not exceed the threshold and differential relay can misoperate.

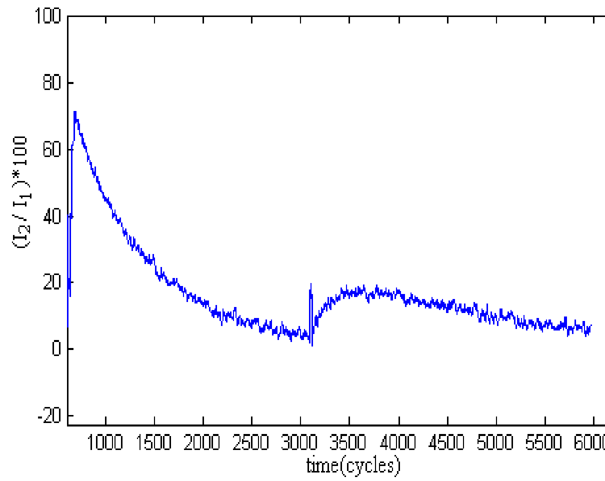

Fig.12 The percentage of the 2^{nd} harmonic to fundamental

IV. CONCLUSIONS

In this paper, the sympathetic interaction between transformers that takes place during the inrush transient has been investigated. The transformer already connected to supply system can experience unexpected saturation during the inrush transient of an incoming transformer.

The sympathetic inrush current may not have a sufficient amount of the second harmonic in it to prevent the relay from tripping. Sympathetic inrush current magnitude is depend on transformer energization angle, magnetic core properties and residual flux. It is seen that the dc voltage drop in the transmission line causing by dc component of inrush current is the major cause of sympathetic inrush. This interaction is greatly reduced if:

a) The line resistance is small
b) The incoming transformer is energized at zero crossing voltage.

If these conditions couldn't respond, the problem can be dealt with satisfactorily by the use of separate differential relays.

V. ACNOWLEDGMENT

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VII. BIOGRAPHIES

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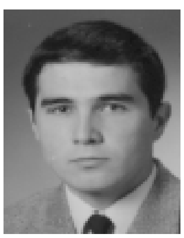

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