Proceedings of the International Conference on
Information Technologies (InfoTech-2014)
20-21 September 2018, Bulgaria

INRUSH CURRENT INTERFERENCE BETWEEN POWER TRANSFORMERS

Mihail Digalovski, Goran Rafajlovski

University St. "Cyril and Methodius", Skopje
Faculty of Electrical Engineering and Information Technologies
mihaild@feit.ukim.edu.mk,
Republic of Macedonia

Abstract: In this paper the transient analysis of the inrush current of parallel connected power transformer is investigated. The MATLAB-Simulink simulation model is developed for the purpose of mathematical validation.
Key words: sympathetic interaction, simulation model, power transformers, inrush current, MATLAB/Simulink

1. INTRODUCTION

When calculating the transient switch-on current, it is usually assumed that the transformer is switched on in a power system in which there are no other transformers. In practice, this situation is almost impossible, i.e. at least one transformer is already connected to the moment when the next transformer is connected.

In the systems with significant serial resistances, such as long transmission lines, the above situation can lead to transient interaction between transformer that is switched on at the moment and those already connected.

The connection of large power transformers can lead to incorrect operation of the differential protection of the other transformers in the system. This is due to the saturation of the already connected transformers as a result of the unexpected voltage drop in the system [3]. The saturation of the remaining transformers is also observed in systems where the transformers are directly connected to synchronous machines, as a result of the overvoltage induced by the response of the automatic voltage regulator to the synchronous generator.

Inrush current impact

It is known that the switching on transient magnetizing current of one transformer is a consequence of the saturation of the transformer core. This dc current, grows sharply to its peak value in the first half-period after the transformer has been switched on, and then decreases to its normal stationary value in subsequent periods.

In general, the amplitude and duration of the transient current depends on:

• The moment of switching on, i.e. the instantaneous value of the supply voltage at the moment of switching on the transformer

• The magnetizing flux maximum value in the transformer core (remanent magnetizing flux) and its direction

• The saturation of the magnetic core

• The total impedance of the inrush current circuit

All this applies if only one transformer participates in a transient phenomenon, ie, for the case when the first transformer is switched on in the system [2]. In cases where there are transformers in the system that are previously connected, the amplitude and duration of the initial current of the transformer which at this moment turns on can significantly deviate from the expected ones. The reason for this is the saturation of the already connected transformers as a consequence of the inrush current of switching on the newly connected transformer. This phenomenon in the literature is known as sympathetic interaction between transformers. Therefore, in addition to the above factors that influence to the inrush current, the next, not so insignificant condition should be added:

• The level of saturation reached by the already connected transformers in the system

This indicates the fact that the established transient influence between the transformer that is switched on in the system and those previously connected can extend the duration of the transient regime of switching on the transformer.

Sympathetic interaction between transformers

Complicated phenomenon, such as the sympathetic inrush current (transmitted saturation), is the topic of recent research in this field.

Transient magnetizing currents of high intensity do not have to flow exclusively in the transformer that switched on but also through the transformers that are already connected to the system. It has also been established that the transient period of these currents is very long and they are decreasing much slower than the transformer's inrush current that would be the only or first in the system.

The simulation model in MATLAB / Simulink is based on the electrical scheme shown in Figure 1. It is assumed that the power system short-circuit impedance Zs in the connection point-bus bar B1 is of high value (weak network).

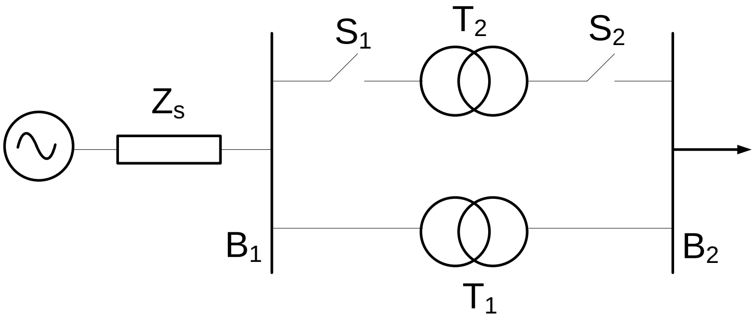

Fig. 1. Power system scheme for inrush current analysis

The Transformer T1 is previously connected and is in a stationary operating regime. At a given time in parallel whit them, the transformer T2 is switched on. As a consequence of the transient current of the T2 switching, a voltage drop of the impedance Zs occurs decreasing the voltage of the bus bar B1. In this case, the transformer T1 begins to be demagnetized. After several damping periods, of the current flowing through power transformer T2, the B1 voltage begins to increase, making the power transformer T1 magnetizing again. It is clear that a inrush current occurs in the transformer T1. This current can lead to a incorrect activation of the differential protection, while turning off the power supply to the consumer.

2. RESEARCH OBJECT

Research object is a three-phase distribution transformer, type ETN 50-10 / 0,4, in oil performance. The nominal data of the analyzed transformer are S_n=50 kVA; U_1/U_2=10/0,4 kV; I_1/I_2=2,89/72,2 A; u_{kn}=4 %; f_n=50 Hz; p=±2x2,5 %; Yz_n5. The analyzed transformer is shown in Fig. 2, and the magnetization characteristic of the transformer core is given in Fig. 3.

Fig. 2. Distribution transformer, type ETN 50-10/0.4

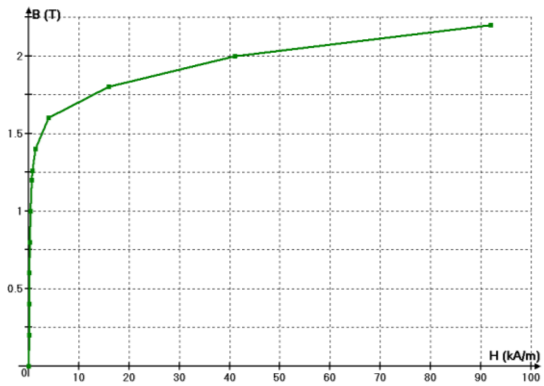

Fig. 3. Magnetizing characteristic of the transformer core

3. MODEL IN MATLAB / SIMULINK FOR ANALYSIS OF SIMPATIC INTERACTION BETWEEN TRANSFORMERS

The single-pole scheme for the analysis of the phenomenon of sympathetic interaction between two transformers is shown in Fig. 4, and the MATLAB / Simulink model is shown in Fig. 5.

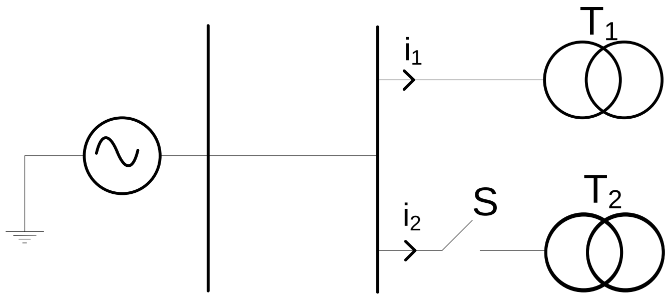

Fig. 4. Connection of T2 transformer in parallel with T1 (single-pole scheme)

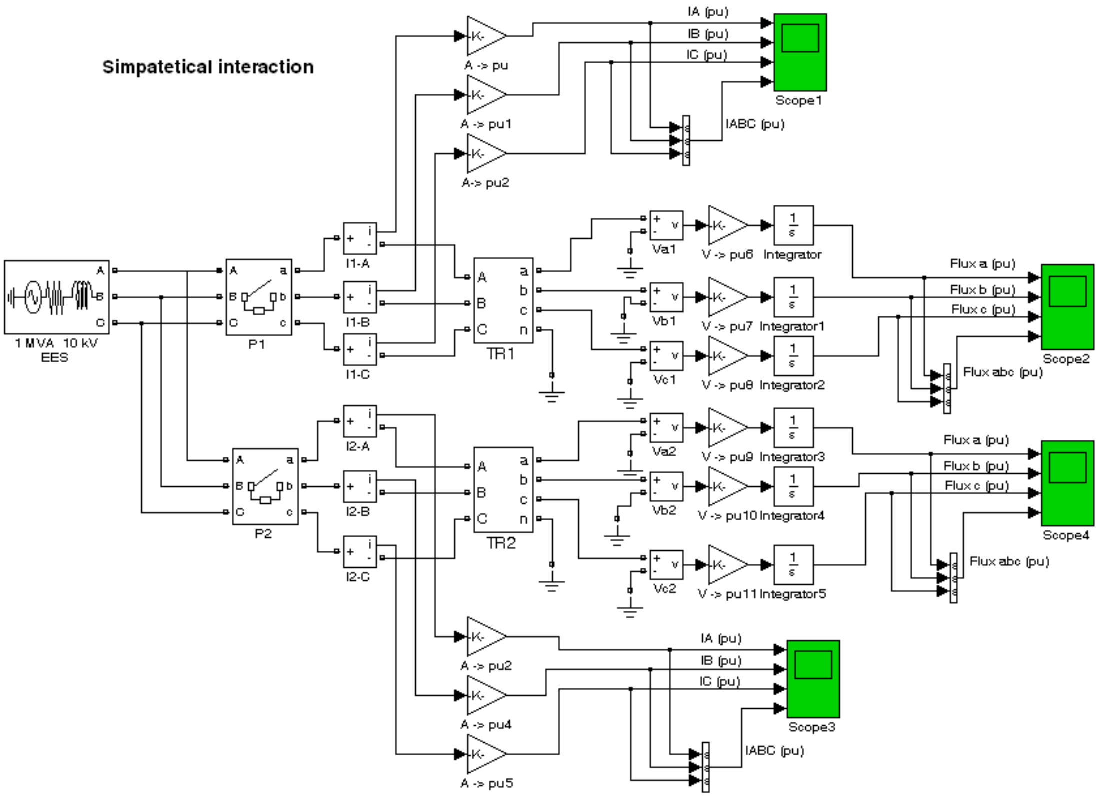

Fig. 5. Simulation model in MATLAB / Simulink for sympathetic interaction analysis between two three-phase transformers

The power supply of the two transformers is realized by a three-phase electric source with its own internal impedance, which is equivalent to the power system [5]. Its internal resistance represents the short-circuit impedance at the point of connection of the transformers (this is the busbar B1 from Fig. 1). The electrical source generates a three-phase voltage system in the model and is tuned so that the voltage in phase A has an initial angle of 0 degrees. The output line voltage at the source is with an effective value of 10 kV, as much as the value of the primary winding voltage of the transformers.

Through two switches suitable for both transformers, the voltage is carried on the primary windings. The switch-on time of the first switch is t_1=0,06 (s), and of the second is t_2=3 (s). The time of the whole simulation is set to t=10 (s). The times are tuned in this manner: first the transformer T1 must be switched on, its transient regime passes. The time when the second transformer is switched on in parallel with the first should be long enough for the first to be entered into stationary regime. After 3 (s) from the beginning of the simulation, the second transformer is switched on and the currents are monitored in both transformers. Also, the total time of the simulation should be long enough for both transformers to enter the stationary regimes and since they are identical, can compare the duration of the transient process when switching the network transformer on its own and in parallel with an already connected transformer. In other words, the time of the transient regime of switching on of the first transformer, which was independent at startup, and the time of the transient switching regime of the second transformer, which is connected in parallel with the first one, will be compared. Calculated switching times of both transformers are taken in the moment when current has the greatest value, and when the voltage drop to zero. The residual magnetism at the core of the transformer is neglected.

Phase A is taken for the reference phase to which the times are set.

To measure the primary currents for each phase individually both current transformers are set current meters. The current signals are monitoring via oscilloscope. Also, the three signals for the individual phase currents with multiplexer are unified in a three-phase signal, which represents the three-phase system of primary currents.

In the transformer blocks, all values for its data and parameters are given, such as: nominal power, nominal primary and secondary voltage, nominal frequency, active and reactive resistance of primary and secondary windings in per units, magnetization characteristic, delta-, or way-connection, and winding vector group[1].

On the secondary terminals of the transformers, voltage sensors are placed, recording the voltage measured signals. Then the multiplier signals turn into single sizes and ultimately led into integrators that exit the flux for each phase individually as an integral of the corresponding phase voltage [4]. Fluxes are further implemented on oscilloscopes, which monitor their change over time.

4. SIMULATION RESULTS

Fig. 6 shows the switching on currents of the transformer T1, and in Fig. 7 the phase fluxes, respectively for each of the phases. For the transformer T2, the switching currents are shown in Fig. 8 and the fluxes in Fig. 9. The figures show that transient phenomena are most dominant in phase A, since that phase is taken as a reference, respectively, and both transformers are switched on at the moment when the phase voltage U_A passes through zero, and then the flux has a maximum value. In the other two phases, the amplitude of the transient inrush current is less than in phase A. If the current in phase A is considered, it can be noticed that when the transformer T1 is switched on in no-load regime, due to the process of magnetizing the transformer core, its amplitude reaches a value of about 70% of the nominal. In the simulation, the two transformers are tuned at the time of switching on to have no residual magnetism in their magnetic circuits. If there is a residual magnetism, other transient phenomena would occur, and the greatest amplitudes of the transient currents occur in the remanent magnetism with the opposite polarity from the magnetic flux that is established at the moment of connection. When the transformer T1 is connected to a network, another transformer is not connected to the terminals and its transient process lasts about 1.5 (s). Then the transformer enters stationary mode and the effective current value is I_0. At the moment t=3 (s), it switches on of the network at the same transformer T2, but now one transformer has already been connected to the network. At that moment in T2 begins the magnetization process and because it is identical to T1, the amplitudes of the inrush currents are the same. Then there is a sharp drop in the terminal voltage, because the short-circuit impedance at that point has a great value ("weak network"). Transformer T1 has a reversible process from that of T2. The T1, which is entered into the stationary regime and its core is magnetized, in case of a sudden drop in voltage, its core begins to be demagnetized and a transient process is called sympathetic interaction between the transformers. The current that occurs in this process is called the sympathetic current of the transformer T1. From Fig. 8, it is noted that the inrush current in phase A of the transformer T2 is more difficult to dampen than in the case when T1 was turned on, as the first transformer in the network. The transient period is much longer and lasts about 8 (s). This is due to the transient interaction of the two transformers, which are already connected in parallel. The duration and influence of the sympathetic current on the power systems i.e. the other transformers depends on various factors. The phenomenon is more evident in transformers with higher power, in high-impedance networks at a short circuit at the point of switching on the transformer. Also, the appearance is more noticeable in transformers with a aged magnetic material. An important role for the amplitude of the inrush current is the combination of the moment of connection and the magnitude of the remnant magnetic flux.

The sympathetic saturation of the transformers is intensive at the first electrification of the transformer substation, especially on no-load mode of operation or at very low loads.

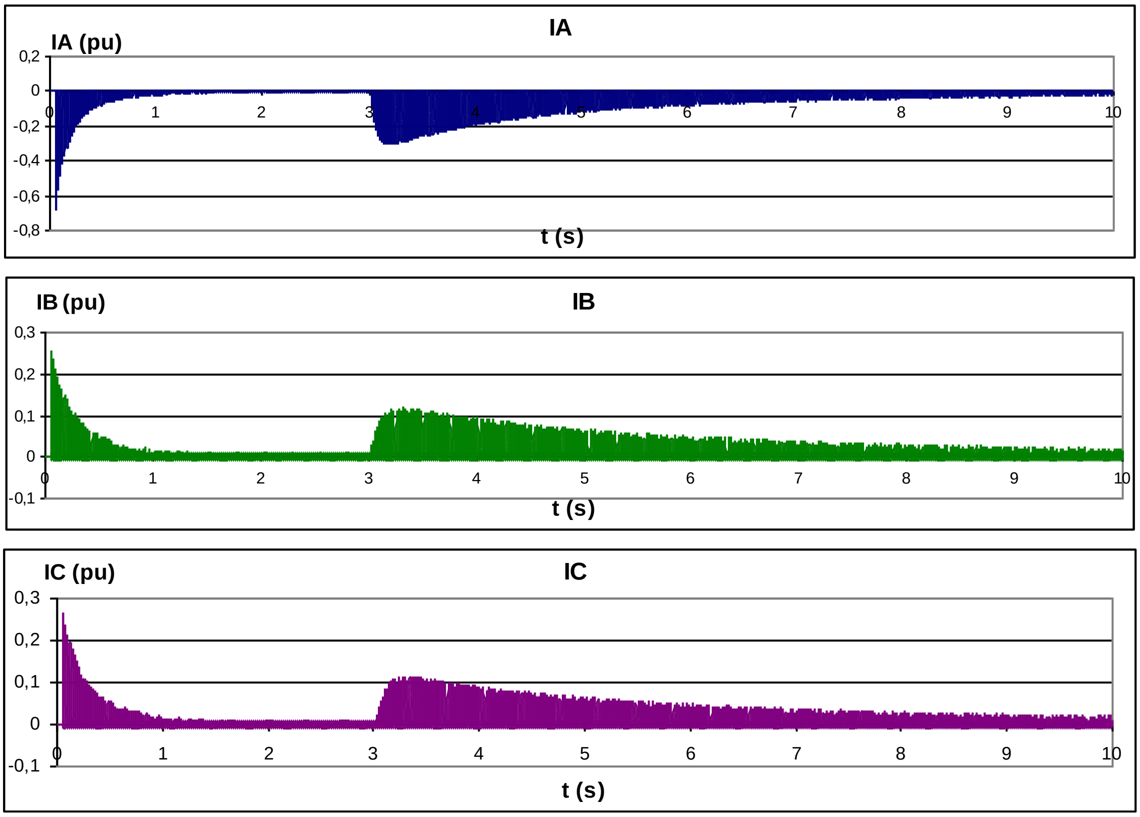

Fig. 6. Inrush current in the transformer T1

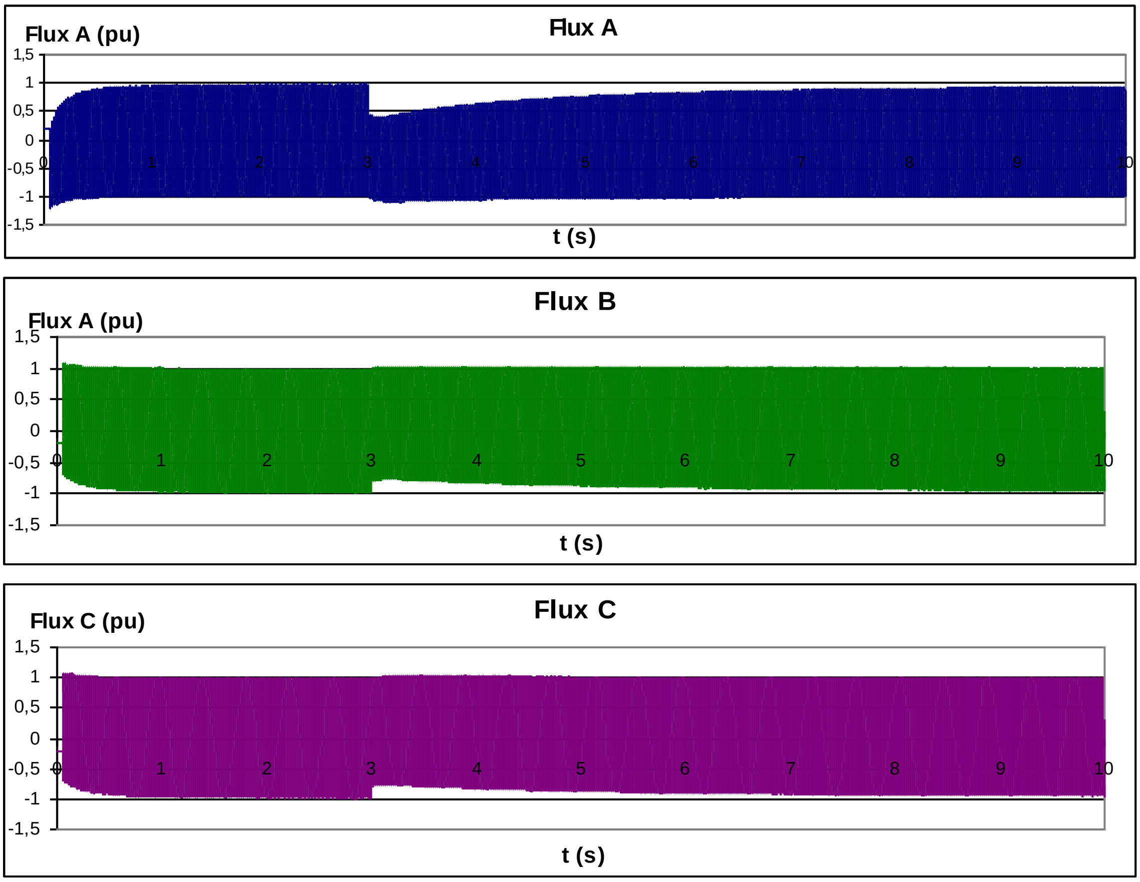

Fig. 7. Phase fluxes when the switching on the transformer T1

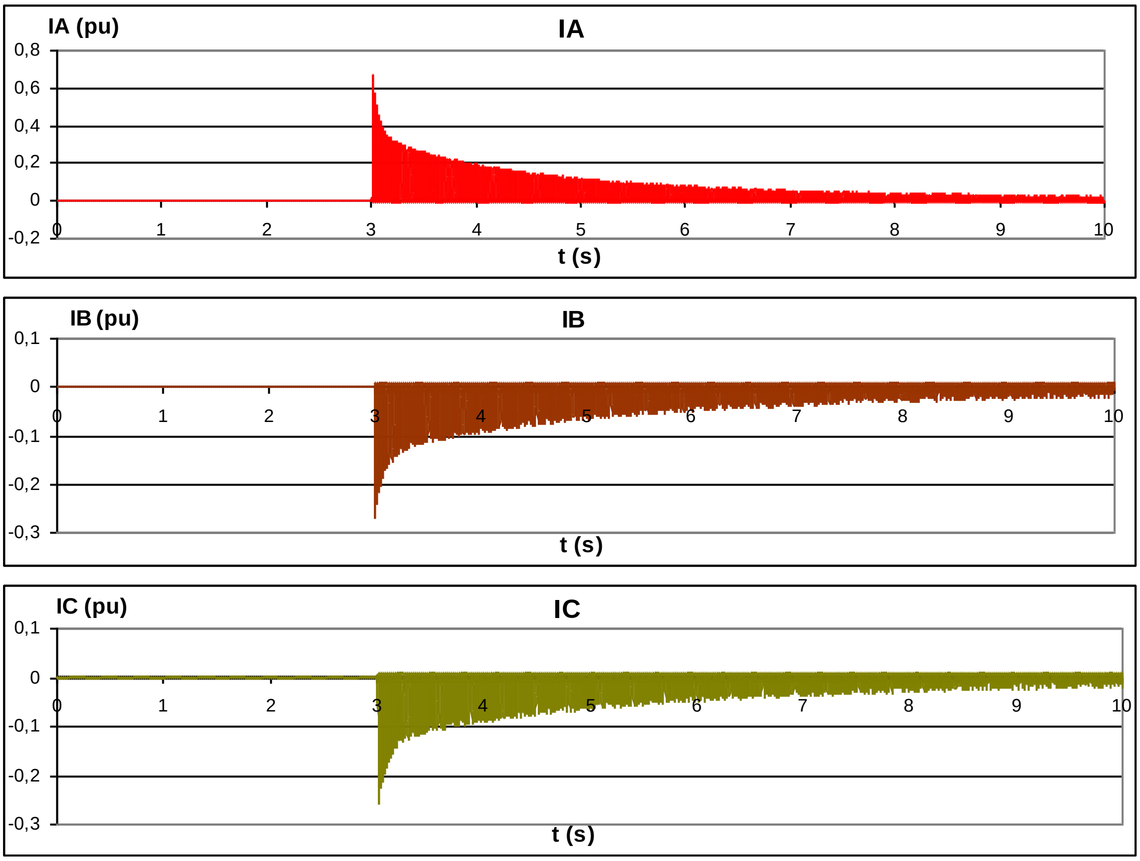

Fig. 8. Inrush current in the transformer T2

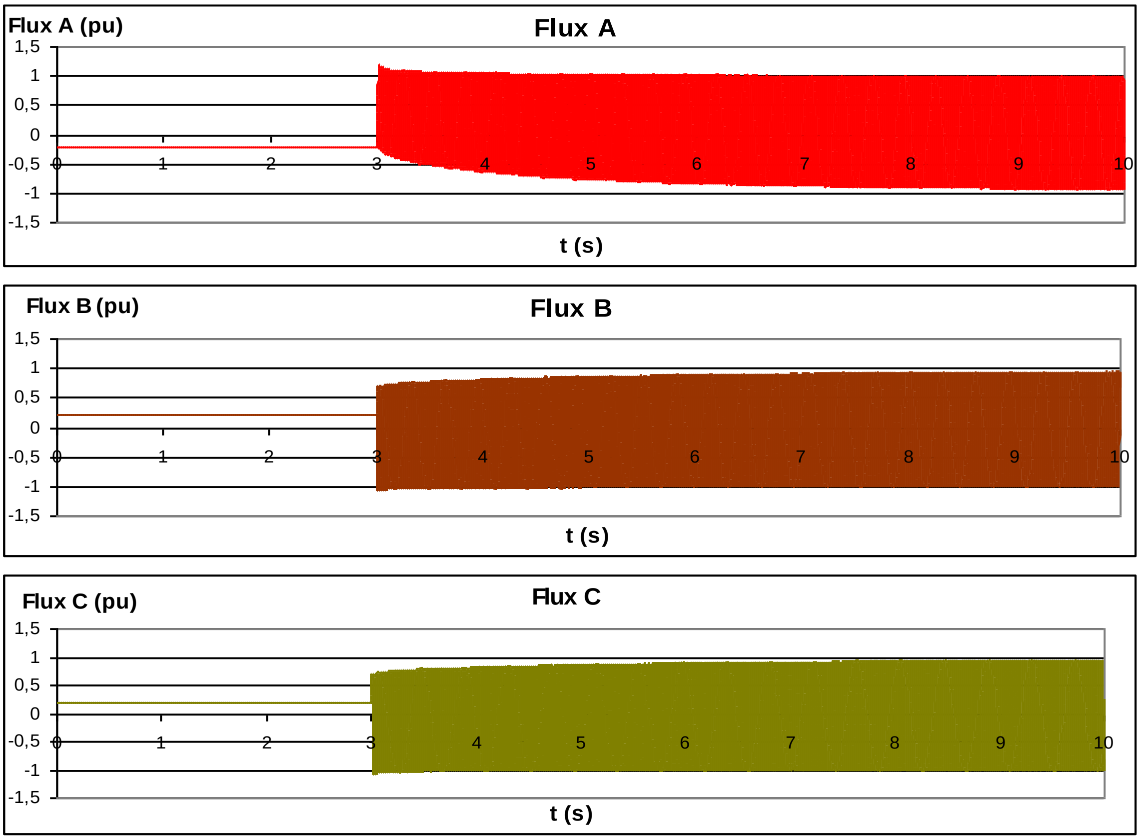

Fig. 9. Phase fluxes when the switching on the transformer T2

5. CONCLUSION

When one unloaded transformer is connected to a network, the primary current does not currently reach its nominal value, but this occurs after the transient period, which is characterized by a current that is significantly increased in the beginning then decreases. It is called an inrush current. This dc current, grows sharply to its peak value in the first half-period after the transformer has been switched on, and then decreases to its normal stationary value in subsequent periods.

The conditions on which the amplitude and duration of the inrush current are dependent were previously mentioned. In worst-case switched on/off conditions, the peak value of the in-line current can reach up to 40 times the rated current of the transformer. The whole phenomenon is generally dampened in a few seconds, but in certain extreme circumstances (for example, in the case of interference between two high-power transformers) it may take even minutes.

The inrush current is not dangerous to the transformer itself that is switched on, but it can affect the protection equipment (over current protection, differential protection, etc.) that can interrupt the electrical circuit and thus disable the switching on/off of the power transformer. Also, due to the sympathetic effect, during the power transformer switching on/off grid procedures, a significant influence may occur on the other transformers in the substation or in one part of the power system. These things indicate that certain preventive measures need to be taken to avoid these unpleasant phenomena in the power systems. Often the preventive measures are aimed for enhancing the inrush current damping and configuring and adjusting the protection schemes in order to avoid unwanted activation in the transient process of switching on the transformer.

Some of the preventive measures to mitigate the impact of these phenomena are:

- Time delay of transformer protection
- Second harmonic control of the transient inrush current, because it has a considerable value
- Identification of the inrush current using the techniques of pattern recognition, as the most modern technique
- Adding the resistance to the series with the primary transformer winding

6. REFERENCES

[1] M. Digalovski, L. Petkovska, K. Najdenkoski (**2012**). Determination of Three-Phase Transformer Reactance's with 3D Finite Element Method. *International Journal on Information Technologies and Security,* No.2, pp.65-72.

[2] M. Popov, L. Van Der Sluis. G. C. Paap and P. H. Schavemaker (**2000**). On a hysteresis model for transient analysis. *IEEE Power Engineering Review*, vol. 20, No. 5, pp. 53-55.

[3] M. Digalovski, K. Najdenkoski, G. Rafajlovski (**2013**). Impact of Current High order Harmonic to Core Losses of Three-Phase Distribution Transformer. *Eurocon 2013*, Zagreb, Croatia, pp. 1531-1535.

[4] S. Ayasun and Chika O. Nwankapa (**2005**). Transformer tests using MATLAB/Simulink and their integration into undergraduate electric machinery courses.

[5] G. Washington and A. Rajagoplan (**2002**). Simulink Tutorial.