MATLAB/Simulink analysis of no-load start-up regime on a three phase transformer, under different start-up conditions

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Abstract – **In this paper is present analysis of the three phase power transformer with software package MATLAB/Simulink at various start-up regimes and conditions of the transformer. Inrush current that occur during the start-up regimes of a three phase transformer can reach extremely high values and cause many problems not only in the transformer but also in a power system. For investigation of this problem is developed simulation model of a three phase transformer in MATLAB/Simulink. In the model the effects of saturation, hysteresis and remanent magnetic flux are taken into account.**

Keywords – **Three phase transformer, MATLAB/Simulink, inrush current, flux, simulation model, transient analysis.**

I. INTRODUCTION

Of all the transitional processes that take place in power transformers, after short circuited terminals on how most dangerous is transitional process of inclusion of the transformer in a power network in no-load regime. Phenomena are even more complex if the level of saturation of magnetic core is greater. The final expression for the change of flux, with inclusion of the network of the transformer in no-load regime is:

$$\Phi = e^{-\frac{t}{T_a}} \Phi_m \cos \omega t_0 - \Phi_m \cos \omega (t_0 + t) \pm \Phi_z e^{-\frac{t}{T_a}}$$

The initial value of start-up current depends on what point in time the primary coil joined the voltage, and the amplitude and polarity of magnetic flux in the magnetic core from the previous exclusion. In time of inclusion (t=0), depending on time t_0 which includes the transformer, there are six typical situations in which you can find a transformer.

1. Starting at t_0=0, zero voltage and without residual magnetism
2. Starting at t_0=0, zero voltage and with residual magnetism with the opposite polarity than that achieved with equivalent voltage conditions
3. Starting at t_0=0, zero voltage and with residual magnetism with the same polarity than that achieved with equivalent voltage conditions
4. Starting at t_0=T/4, maximal voltage and without residual magnetism
5. Starting at t_0=T/4, maximal voltage and with residual magnetism with the opposite polarity than that achieved with equivalent voltage conditions
6. Starting at t_0=T/4, maximal voltage and with residual magnetism with the same polarity than that achieved with equivalent voltage conditions

From the above mentioned cases, the most dangerous cases are under 1, 2 and 3. To obtain the start-up current, you need to know the magnetizing characteristic of the magnetic core B=f(H) and for each value of flux determine the value of the current contract it.

In three phase transformers process of inclusion in individual phases flows different because the magnetic fluxes are displaced 120 ˚ between.

II. OBJECT OF STUDY

The object of study is a three phase power transformer, oil immersed, with wye-wye connection. The rated data for this transformer are: S_n=125 kVA; U_1/U_2=10/0,4 kV; S_i=12 kV; I_1/I_2=7,225/180,63 A; u_{kn}=4 %; f_n=50 Hz; p=±2x2 %; Yy0.

III. MATLAB/SIMULINK MODEL OF THE TRANSFORMER

The short description of transformer model is given in brief. One three phase sinusoidal voltage source is used to supply the transformer model; their voltages are displaced for 120˚, and it represents balanced three-phase power system. The voltage value is setup to the amplitude (peak value) of the transformer primary voltage. Voltage sources are connected with transformer through three-phase circuit breaker which serves as turn-on or turn-off switch. By inclusion of the internal timer in the model, the switch will be used to set-up the time, i.e. the moment for starting the simulation; the only task is to set the breaker to closed position. All outputs and measured signals are converted in per units; this is more convenient when the comparative transient analysis is performed.

First, the primary currents are converted from amperes to per unit value, using the corresponding element in the model. To enable to observe their time changes, all the three signals are connected to the oscilloscope No. 1. In the model the other oscilloscope is used for observing fluxes in the primary windings of the transformer. For the fluxes, the voltage signals are used and converted into corresponding values expressed in per units, too.

The flux in each phase is obtained as the integral of the respective voltage. For this purpose, after the gain is installed in the respective integrator, the flux linkage of the correspondent phase is obtained as an output given in per units; the oscilloscope No. 2 is used to display the transient characteristics of fluxes. It is worth to emphasize another contribution of the developed transformer simulation model. Namely, in the model is added a multiplexer, at which output are presented separately all three phase flux linkages at the same diagram. This is enabling to carry out the comparative analysis of the time change of the phase fluxes more obvious. Further on, it is possible to compare their values at any arbitrary selected instant of time and to analyze the status of the core for each particular phase.

The input values in the model are the voltage and the frequency rating. In the development of the simulation model it is comprehended to have available also the values of the transformer parameters: there are resistance and inductance of the both windings, as well as the impedance representing the magnetizing branch; usually, per unit values are in use. In a particular database is written the magnetizing curve and transformer parameters, which is obtained by the manufacturer. The curve is used when the transformer core is saturated, i.e. when the non-linear case is studied.

In addition the winding connection is defined; in this case, it is prescribed as $Y_g y_g 0$, meaning both windings are connected in star and grounded, while the voltages are in phase. Next to select is whether hysteresis is included in the simulations it means that respective iron losses have to be taken into consideration. Also, the initial values of fluxes (if any) are set-up. These quantities are depending to the conditions in the particular operating regime that is going to be analyzed.

The developed simulation model is presented in Fig. 1.

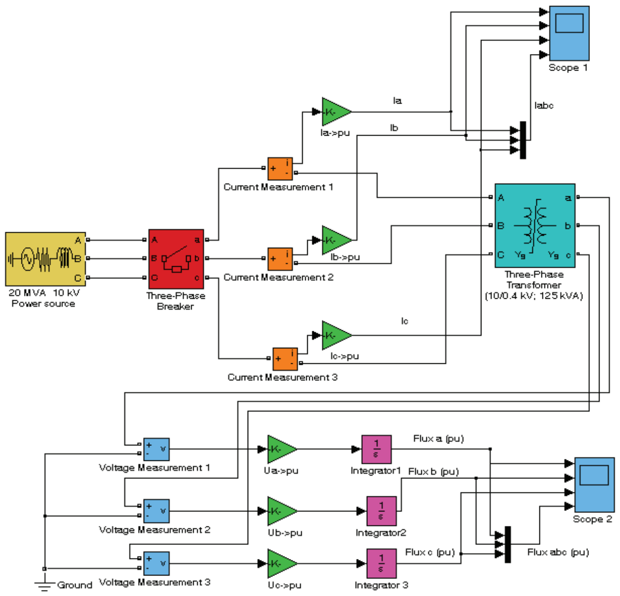

Fig.1. Simulation model of three-phase transformer of no-load regime

IV. MATLAB/SIMULINK RESULTS

A. Starting at t_0=0, zero voltage and without residual magnetism

First case study is a transient process at saturated magnetic core when the initial condition is U_B=0 and without residual magnetism. Transient characteristics of the currents and fluxes are presented in Fig.2 and Fig.3.

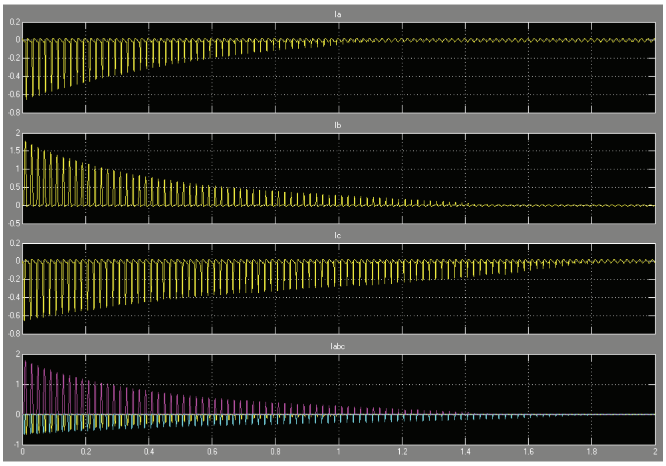

Fig. 2 Currents in the primary winding when U_B=0 and without residual magnetism

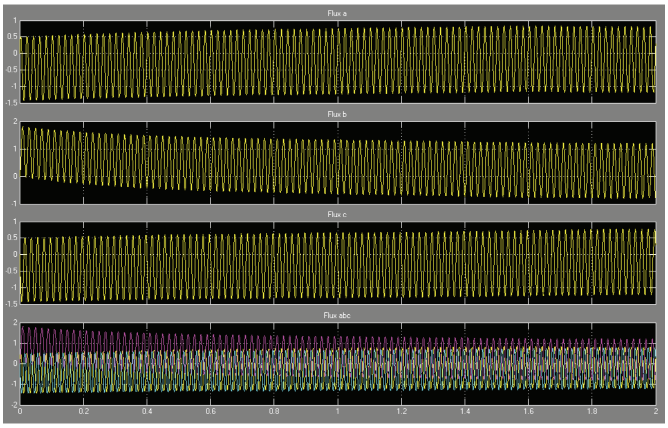

Fig. 3 Fluxes in the primary winding when U_B=0 and without residual magnetism

B. Starting at t_0=0, zero voltage and with residual magnetism with the opposite polarity than that achieved with equivalent voltage conditions

Second case is a transient process at saturated magnetic core when the initial condition is U_B=0 and with residual magnetism with the opposite polarity. Transient characteristics of the currents and fluxes are presented in Fig.4 and Fig.5.

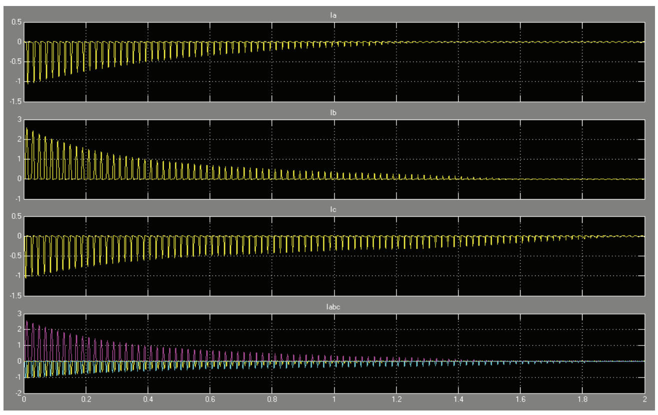

Fig. 4 Currents in the primary winding when U_B=0 and with residual magnetism with opposite polarity

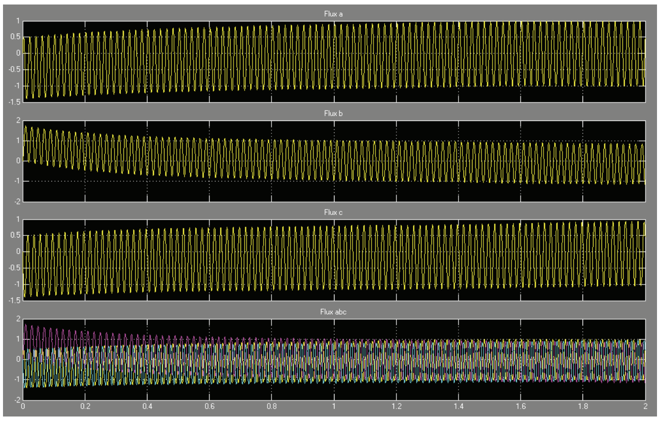

Fig. 5 Fluxes in the primary winding when U_B=0 and with residual magnetism with opposite polarity

C. Starting at t_0=0, zero voltage and with residual magnetism with the same polarity than that achieved with equivalent voltage conditions

Next case is a transient process at saturated magnetic core when the initial condition is U_B=0 and with residual magnetism with the same polarity. Transient characteristics of the currents and fluxes are presented in Fig.6 and Fig.7.

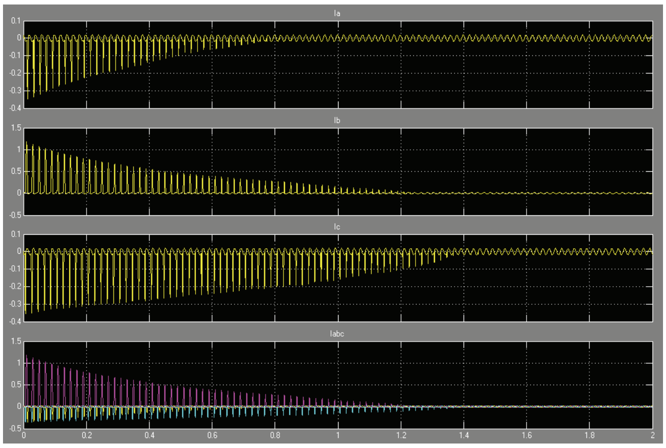

Fig. 6 Currents in the primary winding when U_B=0 and with residual magnetism with same polarity

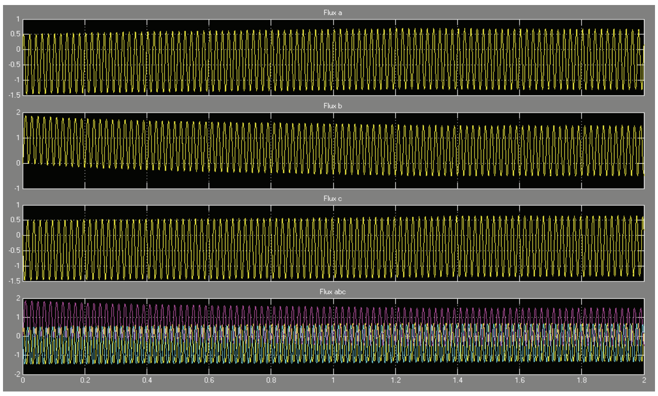

Fig. 7 Fluxes in the primary winding when U_B=0 and with residual magnetism with same polarity

D. Starting at t_0=T/4, maximal voltage and without residual magnetism

First case from the other three cases when $U_B=U_{Bmax}$ is a transient process at saturated magnetic core without residual magnetism. Transient characteristics of the currents and fluxes are presented in Fig.8 and Fig.9.

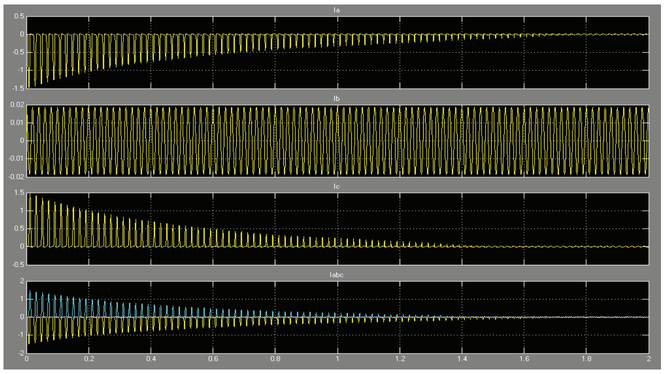

Fig. 8 Currents in the primary winding when $U_B=U_{Bmax}$ and without residual magnetism

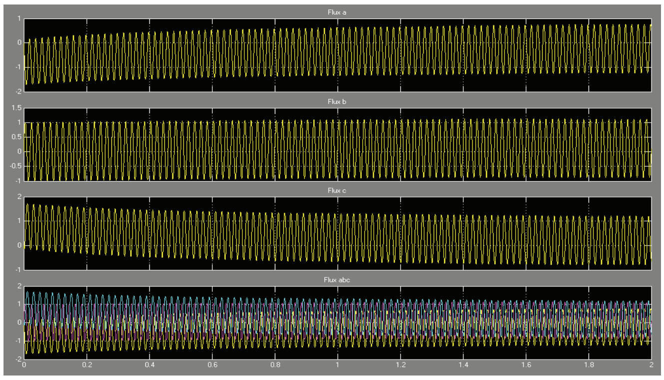

Fig. 9 Fluxes in the primary winding when $U_B=U_{Bmax}$ and without residual magnetism

E. Starting at t_0=T/4, maximal voltage and with residual magnetism with the opposite polarity than that achieved with equivalent voltage conditions

The other case is a transient process at saturated magnetic core when the initial condition is $U_B=U_{Bmax}$ and with residual magnetism with the opposite polarity. Transient characteristics of the currents and fluxes are presented in Fig.10 and Fig.11.

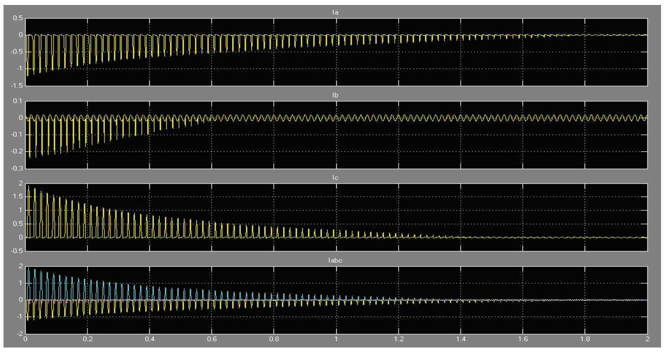

Fig. 10 Currents in the primary winding when $U_B=U_{Bmax}$ and with residual magnetism with opposite polarity

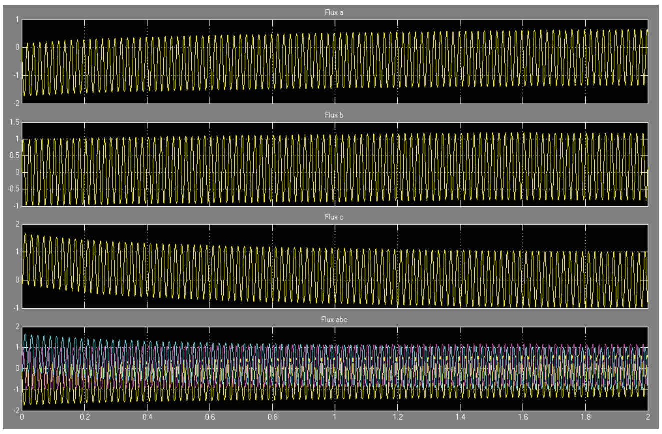

Fig. 11 Fluxes in the primary winding when $U_B=U_{Bmax}$ and with residual magnetism with opposite polarity

F. Starting at t_0=T/4, maximal voltage and with residual magnetism with the same polarity than that achieved with equivalent voltage conditions

The last case study is a transient process at saturated magnetic core when the initial condition is $U_B=U_{Bmax}$ and with residual magnetism with the same polarity. Transient characteristics of the currents and fluxes are presented in Fig.12 and Fig.13.

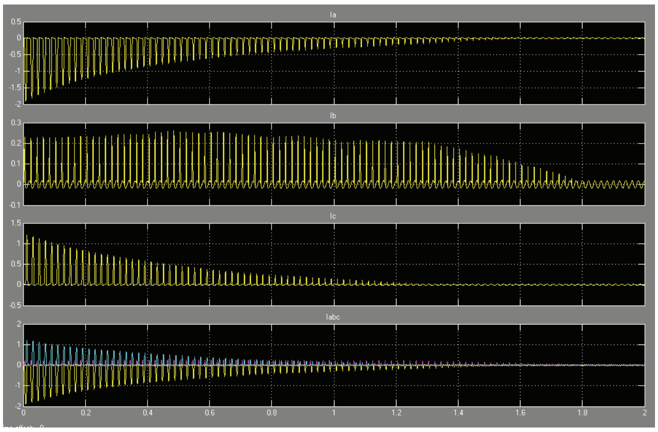

Fig. 12 Currents in the primary winding when $U_B=U_{Bmax}$ and with residual magnetism with same polarity

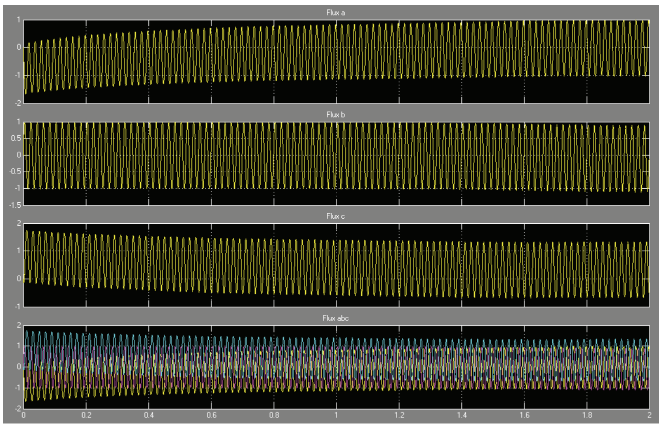

Fig. 13 Fluxes in the primary winding when $U_B=U_{Bmax}$ and with residual magnetism with same polarity

V. Conclusion

In the paper the most typical no-load characteristics at a start up of three phase transformer are presented and analyzed.

The mathematical model of the transformer is implemented in the MATLAB/Simulink environment and transient characteristics are obtained through the particular simulations. For the reference phase is adopted the phase B, which windings are placed on the middle leg of the transformer core. The analysis are carried out under the worst startup conditions, i.e. when the voltage in the analyzed phase passes through zero.

From the detailed observation of the transient characteristics, important conclusion upon the expected quantities of the voltage and currents in the transformer winding are derived. It was shown that under some circumstances it is possible reach that over-currents with values 2-3 times greater than rated value. It can appear incorrect operation of the differential protection of the transformer.

References

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