

SIMULATION OF THREE PHASE THREE LEG TRANSFORMER BEHAVIOR UNDER DIFFERENT VOLTAGE SAG TYPES

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ABSTRACT

Voltage sags are usually caused by energizing heavy loads such as arc furnaces, starting of large motors, single line to ground (SLG) faults, load transferring from one power source to another etc. Voltage sags can cause problems in some electrical equipment such as transformers, induction motors etc. Simulation shows that transformer saturation is produced when the voltage sag is recovered. It produces dc magnetic flux and causes transformer saturation. Inrush current similar to that of transformer energizing is also created. In this paper the effects of voltage sag type, depth and duration are investigated by simulation of a three phase transformer in Matlab environment. It is shown that the current peak has a periodical dependence on sag duration in symmetrical voltage sags. The linear influence of sag depth is observed on the inrush current peak value. It is also shown that unsymmetrical sags can produce current peak as high as those of symmetrical voltage sags.

1. INTRODUCTION

Power quality problems have significant influences on different equipments such as transformers. Voltage sag is a major cause of mal-function of electrical devices and equipment in electrical systems, industrial process, etc [1]. It is reported that the total damages due to voltage sags are higher than other power quality problems [2]. Recently, behaviour of three phase three leg transformer under different voltage sag conditions is investigated. One model for three phase three leg transformer in PSPICE is introduced in [3]. The transformer was modelled with variable characterization of its nonlinear magnetic behaviour. Each leg was viewed as a separate magnetic circuit and a function was proposed to represent core nonlinear behaviour. There was a functional relationship between the magnetic potential in the leg and the flux through it. The model was implemented and the transformer behaviour under different sag depth, duration and initial point on wave in symmetrical voltage sag was reported [4]. Modelling of three phase three leg

transformer operating under different types of voltage sag in PSPICE was implemented and reported in [5]. Unsymmetrical voltage sag effect on transformer and current peak relation with type of voltage sags, duration and depth was investigated.

In this paper a three phase three leg transformer and all type of voltage sags are modelled in MATLAB/SIMULINK environment for simulation purposes. For producing different types of voltage sag a block is created in MATLAB/SIMULINK to take the parameters of voltage sag such as sag duration (Δt), depth (h) and initial point on wave. In the next step the produced voltages are applied to the transformer model separately in order to evaluate the transformer behaviour. The transformer model which was implemented in MATLAB/SIMULINK is based on the previously developed model [3].

2. CHARACTERIZATION AND SIMULATION OF VOLTAGE SAGS

There are different types of voltage sags which are characterized by its magnitude, duration and phase angle jump. Phase angle jump depends on X/R ratio of the source and feeder. Another reason for phase angle jump is the changing of the voltage to lower level [2]. Voltage sags are divided in to 7 groups as types A to G [3].

Three phase faults cause type A which is symmetrical voltage sag. Unsymmetrical voltage sags are due to single phase and phase to phase faults [4]. To clear these faults circuit breakers usually act at zero crossing point of current. The number of sequences for voltage recovery depends on the fault type and can produce 14 sub-groups as described in [3]. Fig.1 shows the block that is implemented in MATLAB/SIMULINK for simulation different types of voltage sag. All type of voltage sag are produced with changing voltage sag characteristics (sag duration (Δt), sag duration (h) and initial point on wave (ψ_i)).

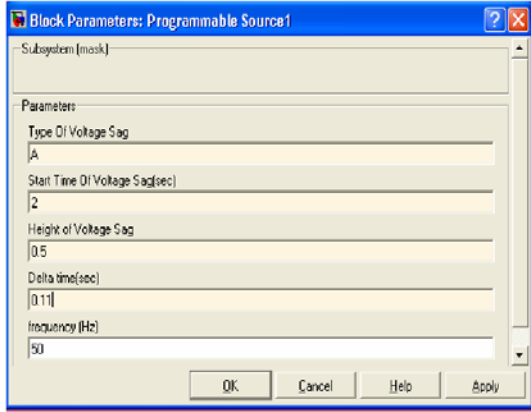


Fig.1. MATLAB/SIMULINK Block for simulation of different types of voltage sags

3. SIMULATION OF THREE PHASE THREE LEG TRANSFORMER

A 60kVA-380/220V-WyeG-WyeG three phase three leg transformer is used for simulation purposes in MATLAB/SIMULINK. Function (1) is used for presenting core nonlinear behavior between magnetic potential in the leg and the flux through it [3].

$$\mathfrak{R}(f)^{-1} = \frac{k_1}{\left(1 + \left(\frac{f}{f_0}\right)^p\right)^{\frac{1}{p}}} + k_2 \quad f_k = \mathfrak{R}_k(f_k)\phi_k \quad (1)$$

where k_1, k_2, p and f_0 are experimental parameters which allow this single-valued function to be fitted to the $(\phi - f)$ transformer saturation curve.

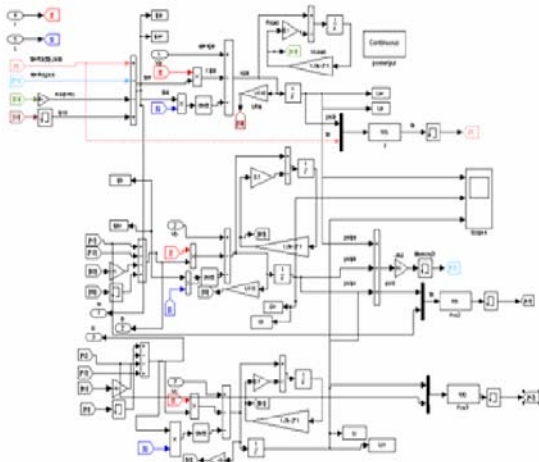


Fig.2. Internal View of Simulated Three-phase Three leg Transformer

Inside view of simulated three phase three leg transformer is shown in Fig.2. Further detail about magnetic and electric circuit are described in [4]. Two important effects of voltage sag are saturation and inrush current in transformers. Inrush current is depended on different

voltage sag characteristics so operation of transformer is considered under different characteristics of voltage sags.

4. TRANSFORMER OPERATION UNDER VOLTAGE SAG

Transformer is simulated under symmetrical voltage sag first. Effects of voltage sag duration, voltage sag depth and initial point on wave on transformer has been investigated where the transformer load is 0.8 p.u.

4-1. SYMMETRICAL VOLTAGE SAG (TYPE A)

Fig.3 shows initial voltage, current and fluxes in a voltage sag with following characteristics: $v(h=0.4, \Delta t=5T, \psi_i=0)$.

In this case no peak current is occurred. This figure shows that no saturation is occurred when initial and final fluxes are equal ($\phi_i = \phi_f$). Fig.4 shows that saturation is

occurred when ($\phi_i \neq \phi_f$). Fig.5 shows inrush current that

is occurred in long term voltage sag with characteristics $v(h=0.4, \Delta t=150.5T, \psi_i=0)$. The current peak has a periodical dependence on sag duration in symmetrical voltage sags. It means that

$i_{peak}(h, \Delta t, \psi_i) = i_{peak}(h, \Delta t + nT, \psi_i)$. Short term voltage sag with following characteristic $v(h=0.4, \Delta t=5.5T, \psi_i=0)$

is also shown in Fig.6 which is similar to Fig 5. It shows that the current peak has a periodical dependence on sag duration.

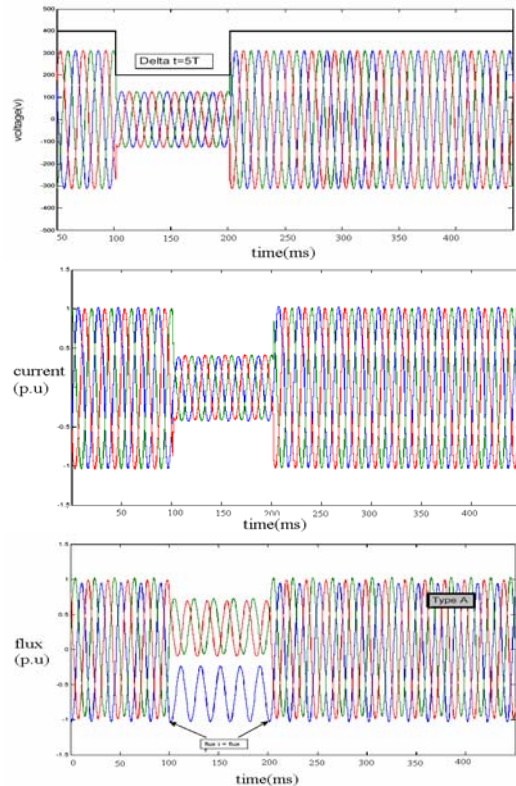


Fig.3. Three phase voltage, current and flux for a sag type $v(h=0.4, \Delta t=5T, \psi_i=0)$

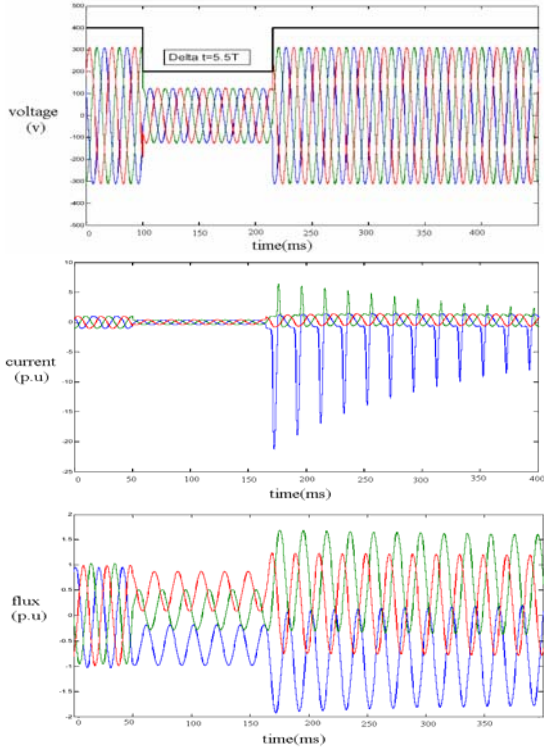


Fig.4. Three phase voltage, current and flux for a sag type $v(h = 0.4, \Delta t = 5.5T, \psi_i = 0)$

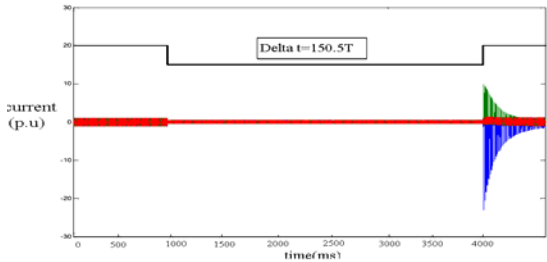


Fig.5. Three phase current for a sag type $v(h = 0.4, \Delta t = 150.5T, \psi_i = 0)$

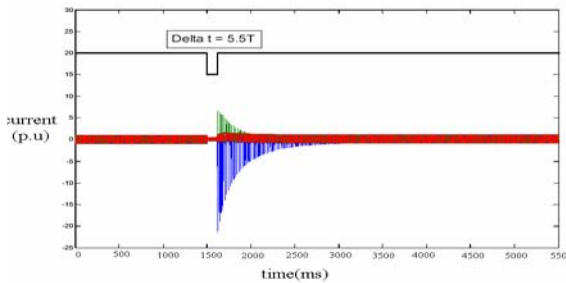


Fig.6. Three phase current for a sag type $v(h = 0.4, \Delta t = 5.5T, \psi_i = 0)$

4-1-1. VOLTAGE SAG DURATION INFLUENCE

4 series of voltage sags with different initial point on wave ($\psi_i = 0 \text{--} \psi_i = 270$) and voltage sag duration

influence on transformer is considered here. Each series has constant initial point on wave and voltage sag depth and different voltage sag duration as:

$$\begin{cases} v_1(h = 0.4, \Delta t, \psi_i = wt_i = 0^\circ), \Delta t \in [5T \dots 6T] \\ v_2(h = 0.4, \Delta t, \psi_i = 90^\circ), \Delta t \in [5T \dots 6T] \\ v_3(h = 0.4, \Delta t, \psi_i = 180^\circ), \Delta t \in [5T \dots 6T] \\ v_4(h = 0.4, \Delta t, \psi_i = 270^\circ), \Delta t \in [5T \dots 6T] \end{cases}$$

Fig.7 shows clearly that maximum inrush current is occurred when $\psi_i = 0^\circ$ or $\psi_i = 180^\circ$ and ($\Delta t = nT + 1/2$) when $n=1, 2, 3$ and etc.

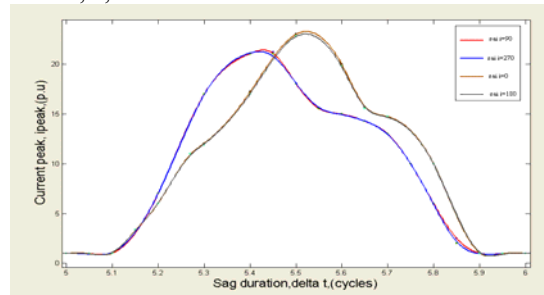


Fig.7. Maximum inrush current versus different voltage sag duration in voltage sag type A with $h=0.4$

4-1-2. VOLTAGE SAG DEPTH INFLUENCE

Influence of voltage sag depth is considered here with the following characteristics :

$$\begin{cases} v_1(h, \Delta t = 5.5T, \psi_i = 0^\circ), h \in [0 \dots 0.9] \\ v_2(h, \Delta t = 5.4T, \psi_i = 0^\circ), h \in [0 \dots 0.9] \\ v_3(h, \Delta t = 5.3T, \psi_i = 0^\circ), h \in [0 \dots 0.9] \\ v_4(h, \Delta t = 5.2T, \psi_i = 0^\circ), h \in [0 \dots 0.9] \\ v_5(h, \Delta t = 5.1T, \psi_i = 0^\circ), h \in [0 \dots 0.9] \\ v_6(h, \Delta t = 5T, \psi_i = 0^\circ), h \in [0 \dots 0.9] \end{cases}$$

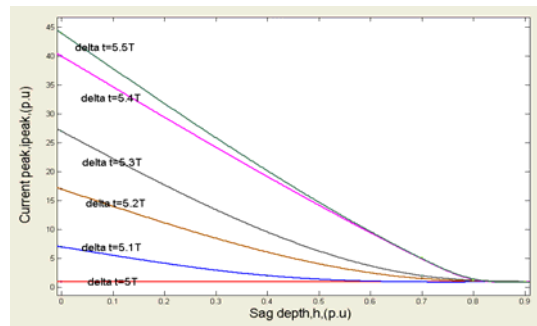


Fig.8. Maximum inrush current versus different voltage sag depth ($h=0-0.9$)

This figure shows that voltage sag depth influence on maximum inrush current is linear.

4-2. UNSYMMETRICAL VOLTAGE SAGS

All type of voltage sags are simulated and voltage sag parameters variation influence on transformer's inrush current is studied. Effect of two examples of voltage sag types (A_3 & E_1) on transformer's inrush current is shown first. Results of others type of voltage sag effects on inrush current are studied in the next step.

4-2-1. VOLTAGE SAG TYPE A_3

Figure 9 shows inrush currents when voltage sag type A_3 with characteristics ($h=0.4, \Delta t = 5.5T$) is occurred. Voltage sag has three step for clearing. Average dc flux is moved from zero value when voltage is recovered. Inrush current is produced when saturation is occurred too.

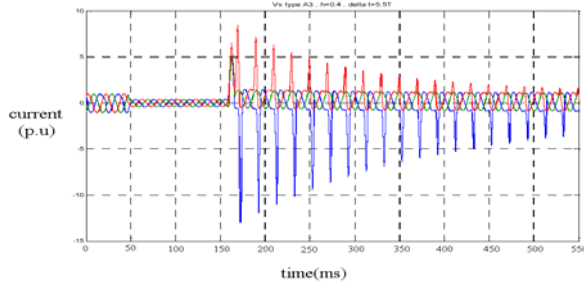


Fig.9. Three phase current for a sag type A_3 : $h=0.4, \Delta t = 5.5T$

4-2-2. VOLTAGE SAG TYPE E_1

Figure 10 shows the transformer behaviour under voltage sag type E_1 with characteristics ($h=0.4, \Delta t = 5.4T$). It shows a case where one current peak is occurred when the voltage drops and another current peak is produced when the voltage recovers.

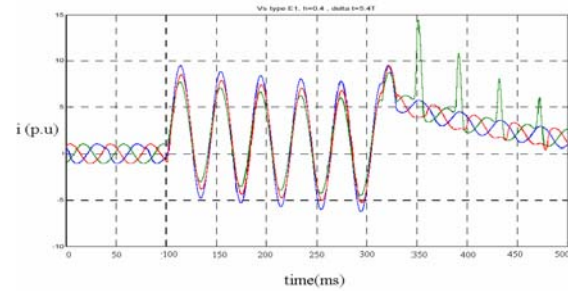


Fig.10. Three phase current for a sag type E_1 : $h=0.4, \Delta t = 5.4T$

4-2-3. VOLTAGE SAG DURATION INFLUENCE

Fig.11 shows three phase current when duration of sag type B is varied. It shows that saturation is occurred when $\Delta t = nT$ and $n=1, 2, \dots$ while in voltage sag type A no current peak was occurred. In opposite manner of type A maximum current peak is occurred when $\Delta t = nT + 1/4$. The transformer behavior caused by type E sags (E_1 and E_2) is different since some of the current peak values in Fig.12 are produced when voltage drops, and the remaining current peak values are produced when voltage

increases. The current peaks produced when voltage recovers for these sag types are drawn with broken line in Fig.12.

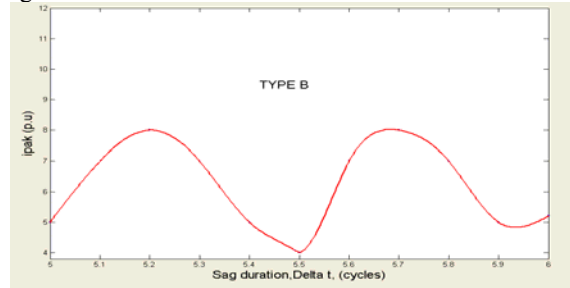


Fig.11. Sag duration influence on the current peak for sag type B with $h=0.4$

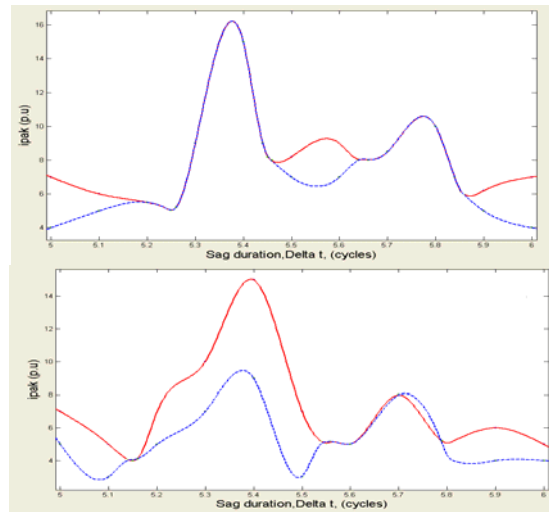


Fig.12. Sag duration influence on the current peak for sag type E_1 and E_2 with $h=0.4$

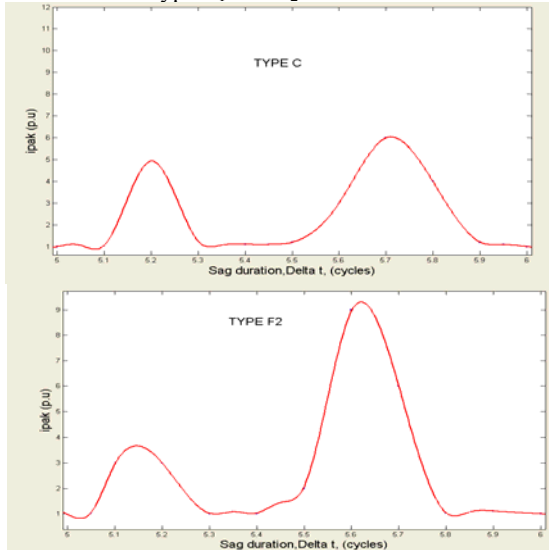


Fig.13. Sag duration influence on the current peak for sag type C and F_2 with $h=0.4$

Current peak for type C and D (Fig 13) are produced when voltage recovers and their values are lower than those of type A sags.

4-2-2. VOLTAGE SAG DEPTH INFLUENCE

Voltage sag depth influence on the current peaks have been considered. Almost a linear influence can be observed for all sag types (Fig.14).

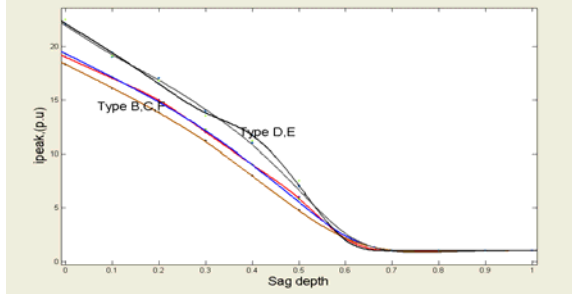


Fig.14. Voltage sag depth influence on the current peak for unsymmetrical sag types.

5. CONCLUSION

The behaviour three phase three leg transformers under different type of voltage sag is investigated in this paper. Symmetrical and unsymmetrical voltage sags are simulated and applied to the transformer model which was implemented in MATLAB SIMULINK environment. In order to produce different types of voltage sag a block is created which takes the voltage sag parameters related to the different voltage sags. Transformer saturation, dc magnetic flux variations, inrush current peak etc are studied using various simulations. It is shown that the voltage sag depth has direct role on increasing the current peak when the voltage recovers. However, the current peak and saturation are highly depended on the initial point on wave during recovery process. It is shown that no

saturation is occurred when $\Delta t = nT$ and maximum current peak is produced when $\Delta t = nT + T/2$. According to the simulation results, voltage sag depth influence on inrush current peak is almost linear.

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