Mitigation and Analysis of Three Phase Transformer Magnetizing Inrush Current By Using Point on Wave Switching Method

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Abstract— Transformer is the most important equipment of the electrical power system. At the time of transformer energization high current is drawn by the transformer known as the inrush current. This current is nearly ten times more than the full load current of transformer. It produces mechanical stress on transformer and also affects the windings and bushings of the transformer. The large switching transient current affects malfunction of protection system of power system and the different equipments connected to system. So the inrush current should be minimized. There are different methods used to minimize the inrush current such as volt second balance, series compensator, point on wave switching method etc. This paper focuses on point on wave switching method. It also explains the results for inrush current of three phase transformer with and without point on wave switching method. A test is driven on 450 kVA, 500kV/230kV grounded Y/D transformer in MATLAB/SIMULINK environment. It also focuses on power quality issues associated with transformer at no load condition.

Keywords— Transformer, point on wave switching, MATLAB R2010a/SIMULINK.

I. INTRODUCTION

Transformer is used at transmission to step up the voltage level and at distribution to step down voltage. But there are some losses and affects due to transformer. Mainly inrush current is occurred in transformer. At the time of transformer energization, a high current will be drawn by the transformer. The mentioned current is called transient inrush current and it may rise to ten times the nominal full load current of transformer during operation. Transformer inrush currents can be divided into three categories, energization inrush, recovery inrush and sympathetic inrush. The first, energization inrush results from reapplication of system voltage to a transformer which has been previously de-energized. The second, recovery inrush occurs when transformer voltage is restored after having been reduced by a nearby short circuit on system. The third, sympathetic inrush can occur when two or more transformers are operated in parallel.

The value of the transformer inrush current is a function of various factors, such as the switching angle of the terminal voltage, the residual flux of the core, the transformer design, the power system impedance, and others. Holcomb [9] proposes an improved analytical equation for the inrush

\[ i(t) = \sqrt{2U} \left( \frac{\sin(\omega t - \varphi) - e^{-\frac{R}{L_{\text{air-core}}}(\omega t - \varphi)}}{\sqrt{R^2 + \omega^2 L_{\text{air-core}}^2}} \right) \]

Where, \( \varphi = \tan^{-1} \frac{\omega L_{\text{air-core}}}{R_W} \)

In section V, analysis of inrush current for three phase transformer is carried out in Matlab/Simulink environment. Finally a brief discussion and conclusion is drawn on transformer inrush current in section VI-VII.

II. INRUSH CURRENT

At the time of transformer energization, a high current will be drawn by the transformer. The mentioned current is called transient inrush current and it may rise to ten times the nominal full load current of transformer during operation. Transformer inrush currents can be divided into three categories, energization inrush, recovery inrush and sympathetic inrush. The first, energization inrush results from reapplication of system voltage to a transformer which has been previously de-energized. The second, recovery inrush occurs when transformer voltage is restored after having been reduced by a nearby short circuit on system. The third, sympathetic inrush can occur when two or more transformers are operated in parallel.

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Where \( U \) is the applied voltage; is the winding resistance; \( L_{\text{air-core}} \) is the air-core inductance of winding; and \( t_s \) is the time when the core begins to saturate \( (B(t) > B_s) \).
III. CAUSES OF INRUSH CURRENT

The main causes of transient inrush current are as moment of switching, residual flux. Transformer is highly inductive in nature. Thus current lags voltage by 90° as shown in fig.1.

Fig. 1. Transformer energization when voltage is at 0°

As shown in fig. 2, when transformer energized at 0 degree the value of flux and current are at negative peak. Thus the flux increase at the higher rate and it becomes twice the value of flux in steady state condition. This higher value leads to increasing the current ten to fifteen times the rated value.

Fig. 2. Transformer energization when voltage is at peak

As fig.2 when the transformer are energized at its positive peak value of instantaneous voltage i.e at 90° at this instant the value of current and flux are zero. In order for the transformer to create an opposing voltage drop to balance against this applied source voltage, a magnetic flux of rapidly increasing value must be generated. The result is that winding current increases rapidly, but actually no more rapidly than under normal conditions.

IV. EFFECTS OF INRUSH CURRENT

The inrush current affects whole power system. It mainly affects on transformer, protection system, equipments connected to system and raises power quality issues [7] [4] [2].

A. Transformer

As the inrush current increases the temperature increases by the theory of effect of negative temperature. So the temperature of bushings and the windings increases [7].

B. Protection system

In protection system relay is important equipment. It senses the short circuit or abnormal conditions of system to isolate and protect the system. The short circuit of transformer is always less than inrush current [4]. It is hence sensed by relay system, such that transformer is isolated from system which is unexpected. Thus inrush current causes malfunction of protective system. As transformer gets isolated due to effect on protection system there is interruption of system [1].

C. Power quality

The presence of harmonic content in inrush current causes wrong analysis with medical equipments. It also affects to heat rise of the system [1].

V. ANALYSIS OF INRUSH CURRENT IN MATLAB/SIMULINK

Matlab is user friendly software with simpower system toolbox. A test is driven on 450 kVA, 500kV/230kV grounded Y/D transformer in MATLAB/SIMLINK environment.
Analysis is done on inrush current of three phase transformer as shown in fig. 4. The switching time for circuit breaker is changed from its parameter settings.

The switching time of circuit breaker is changed from 0° to 30°, 60° and 90° and various results are observed and analyzed. The calculations for switching angle are given as below:

- Time duration for 50 cycles = 1000 msec
- 1 cycle = 1000/50 = 20 msec
- For switching at peak of voltage waveform with phase A, B and C 90° apart:
  - Phase A peak is at 90° = 0.005 sec
  - Phase B peak is at 90 + 120 = 210° = 0.0116
  - Phase C peak is at 90 + 240 = 330° = 0.01833

VI. RESULT ANALYSIS AND DISCUSSIONS

Fig. shows the inrush current drawn by transformer without point on wave switching
Table I explains the magnitude values of current and voltage at different switching angle. It shows that the value of current at 0° is too high and when the switching are provided at 90° by using point on wave switching method current value get reduced to lower value.
Fig. 12. THD analysis for voltage of R phase at 90°

Table II
Second Harmonic at 0°

<table>
<thead>
<tr>
<th>S/W</th>
<th>phase</th>
<th>I(H2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>A</td>
<td>11.74</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>31.74</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>34.92</td>
</tr>
</tbody>
</table>

Table III
Second Harmonic at 30°

<table>
<thead>
<tr>
<th>S/W</th>
<th>Phase</th>
<th>I(H2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>A</td>
<td>22.66</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>52.20</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>74.93</td>
</tr>
</tbody>
</table>

Table IV
Second Harmonic at 60°

<table>
<thead>
<tr>
<th>S/W</th>
<th>Phase</th>
<th>I(H2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60°</td>
<td>A</td>
<td>38.20</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>87.59</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>85.65</td>
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</table>

Table V
Second Harmonic at 90°

<table>
<thead>
<tr>
<th>S/W</th>
<th>Phase</th>
<th>I(H2%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90°</td>
<td>A</td>
<td>64.98</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>101.30</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>99.47</td>
</tr>
</tbody>
</table>

Tables II-V explains the value of second harmonic component for three phases at different switching angles.

In above table the harmonic order is given in which second harmonic value is more.

VII. CONCLUSION

This paper discusses various inrush current with and without point on wave switching method. Current significantly reduces with point on wave switching method. Also THD for various conditions of switching are mentioned.
In all conditions the second order harmonics component found upper magnitude as compared to others, thus the second order harmonics restraining protective system can be designed in order to minimize hazards to protective system.

REFERENCES


