Evaluation of Losses and Lifetime Degradation on Distribution Transformers for On-Grid Photo-Voltaic Sources

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Abstract— Unlike usual operation of distribution transformers, PV transformers are injected by different characteristic of load: intermittent, harmonics and different load profiles. The transformers are imposed by additional stresses due to harmonics, voltage fluctuations, and peak load happens at midday when the ambient temperature reaches the maximum value. This paper presents calculations and evaluation of iron loss and copper loss due to load and voltage fluctuations, harmonics, and ambient temperature base on measuring data. Then, dynamic thermal model of PV transformers can be constructed for evaluation of the transformer’s lifetime.

Index Terms— PV Transformers, Distribution Transformers, Harmonics, Transformer Loss, Thermal Model, Loss of Life

1. INTRODUCTION

The transformer used to canalized PV sources to distribution grid is a distribution transformer by using newest PLN Standard for distribution transformer: SPLN D3.002-1 2007. This new standard is issued to improve an as a revision on old standard, SPLN 50:1997. The changes are emphasized on:

1. Transformer losses (iron loss and copper loss) as regards of the escalation of production cost.
2. Oil preservation system is stated as hermetically-sealed filled to suppress of maintenance cost.
3. Improvements in core and winding designs.

Table 1. Typical Core Specification Of Manufacture For SPLN Transformers

<table>
<thead>
<tr>
<th>No</th>
<th>Properties</th>
<th>Unit</th>
<th>SPLN D3 - 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Material</td>
<td>CRGO M-3 MOH</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Maximum flux density</td>
<td>Tesla</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>Thickness</td>
<td>mm</td>
<td>0.23 (25 – 50 kVA) 0.27 (100 – 630 kVA)</td>
</tr>
<tr>
<td>4</td>
<td>Knee point of saturation</td>
<td>Tesla</td>
<td>1.9</td>
</tr>
</tbody>
</table>

2. CALCULATION OF DISTRIBUTION TRANSFORMER SUBJECTED TO PV SOURCE

2.1. Transformer Losses

The components of the no-load losses of the transformers are only the eddy-current loss and the hysteresis loss. One of the methods used for separating the no-load losses for transformers is two-frequency method. This method is used since the no-load loss is available at two frequencies in many laboratories and manufacturers.

\[ P(f_1) = P_1(f_0) \left[ \frac{f_1}{f_0} \right] + P_2(f_0) \left[ \frac{f_1}{f_0} \right]^2 \]  

(1)

According to Steintmetz equation, no-load losses are given by following equation :

\[ P_{NL} = K_{IR} f_0 B_m^a + K_{EC} B_m^2 f_0^2 \]  

(3)

And with influence of harmonics,

\[ P_{NL} = \sum_{i=1}^{n} P_{Hn} K_{f1} K_{B1}^2 + P_{ECn} K_{f1}^2 K_{B1}^2 \]  

(4)

The total loss in the winding can be expressed,

\[ P_L = P_R + P_{EC} + P_{OSL} \]  

(5)

2.2. Complete Model of Thermal Aging

No-load loss and load loss calculation blocks are the integrated parts of this thermal model. This model is based on IEC 354 Loading Guide for oil immersed transformers that is similar with IEEE Std C57.91. The main block of this model is hot spot model, which the inputs are losses model, ambient temperature, and thermal characteristics of distribution transformer as well as geometric characteristics of transformer.
3. RESULT AND DISCUSSION

This simulation is done for CRGO M-3 core that designed for SPLN D-3 standard. At nominal value $f = 50$ Hz and $V = 400$ V, gives hysteresis loss 288.4 W, eddy current loss 206 W, and total no-loss load 494.446 W.

Harmonics contents in voltage wave also have impact on no-load loss. Increasing and decreasing of harmonics components to fundamental can change the THDv value. Output of simulation with variation of THDv in Fig. 4 explains how much harmonics affect the no-load loss.

4. CONCLUSIONS

1. The rise of load current will increase the loss quadratically, but the impact of voltage is more linear since the fluctuations flux density are kept in linear region because of the use of transformer with low operating flux density at 1.5 Tesla. So, the new PLN standard: SPLN D3.002-1 2007 is better than former standard in response of voltage fluctuations.

2. In PV transformers, the composition of no-load loss is bigger than load loss since they are operated in very low load factor.

3. The PV transformer tested in simulation have very high life expectancy because of very low load factor, high installed capacity and short (12 hours) normal operation in a day. Harmonics have no significant effect to transformer’s aging because the advance of inverter technology can guarantee the output is in low THD.

REFERENCES


