

ABSTRAK

SABASTIAN HALOMON SIHOMBING. SIMULASI PENGARUH VARIASI BEBAN TERHADAP RUGI-RUGI DAYA DAN JATUH TEGANGAN PADA TRANSFORMATOR 1 MVA MENGGUNAKAN PERANGKAT LUNAK ETAP VERSI 19.0.1.

Dibimbing oleh Muchamad Nur Qosim, S.T., M.T.

Transformator distribusi memegang peran esensial dalam menyalurkan energi listrik ke instalasi konsumen. Dalam operasionalnya, transformator selalu dihadapkan pada fluktuasi penarikan beban yang memengaruhi stabilitas kinerjanya. Peningkatan beban yang ekstrem akan memicu lonjakan rugi-rugi daya yang berdampak pada panas berlebih (thermal stress). Jika batas toleransi termal terlampaui, kekuatan material isolasi di dalam transformator akan terdegradasi, yang pada akhirnya berpotensi memicu kegagalan sistem secara menyeluruh. Mengingat pengujian kerusakan isolasi secara langsung di lapangan memiliki risiko tinggi, diperlukan analisis preventif yang komprehensif.

Penelitian ini bertujuan untuk mengevaluasi pengaruh variasi pembebanan terhadap profil jatuh tegangan, rugi daya aktif, serta tingkat keamanan operasi pada transformator 1 MVA. Eksperimen komputasi dilakukan menggunakan perangkat lunak Electrical Transient Analyzer Program (ETAP) versi 19.0.1 sebagai instrumen pendukung keputusan (decision support tool). Simulasi Load Flow Analysis dieksekusi dengan lima skenario pembebanan (25%, 50%, 75%, 100%, dan 120%). Data luaran dari ETAP kemudian dianalisis menggunakan pendekatan tidak langsung melalui pemodelan matematis termal berdasarkan standar kelistrikan internasional IEEE C57.91 dan IEC 60076-7.

Hasil simulasi menunjukkan adanya korelasi eksponensial antara beban dan rugi daya. Pada beban 25%, rugi daya terukur minim sebesar 0,9 kW dengan jatuh tegangan 0,93%. Namun, pada kondisi overload 120%, rugi daya melonjak drastis hingga 21,0 kW dengan jatuh tegangan mencapai 4,66%. Angka deviasi rugi daya sebesar 45,8% dari kondisi nominalnya bertindak sebagai indikator awal anomali termal. Berdasarkan analisis perhitungan model termal, rugi daya ekstrem tersebut terbukti memicu kenaikan suhu hot-spot pada belitan hingga mencapai 131,33 °C. Suhu yang melampaui batas standar desain ini menyebabkan laju penuaan isolasi (Factor of Accelerated Aging) berlangsung 7,89 kali lebih cepat, dan memicu susut umur operasional (Loss of Life) sebesar 23,67 jam untuk setiap 3 jam kondisi overload. Kesimpulannya, pembebanan berlebih terbukti secara matematis mempercepat degradasi isolasi akibat tekanan termal tinggi, sehingga pengoperasian transformator pada titik marjinal tersebut sangat tidak direkomendasikan.

Kata kunci: ETAP 19.0.1, IEC 60076-7, Jatuh Tegangan, Rugi Daya, Suhu Hot-Spot, Transformator 1 MVA.

ABSTRACT

SABASTIAN HALOMON SIHOMBING. SIMULATION OF THE EFFECT OF LOAD VARIATION ON POWER LOSSES AND VOLTAGE DROP IN A 1 MVA TRANSFORMER USING ETAP VERSION 19.0.1 SOFTWARE.

Supervised By Muchamad Nur Qosim, S.T., M.T.

Distribution transformers play an essential role in distributing electrical energy to consumer installations. In their operation, transformers are constantly faced with fluctuations in load demand that affect their performance stability. Extreme load increases will trigger a surge in power losses resulting in excessive heat (thermal stress). If the thermal tolerance limit is exceeded, the strength of the insulation material inside the transformer will degrade, which ultimately has the potential to trigger total system failure. Considering that direct testing of insulation damage in the field carries high risks, a comprehensive preventive analysis is required.

This study aims to evaluate the effect of load variations on the voltage drop profile, active power losses, and the level of operational safety in a 1 MVA transformer. Computational experiments were conducted using the Electrical Transient Analyzer Program (ETAP) version 19.0.1 software as a decision support tool. The Load Flow Analysis simulation was executed with five loading scenarios (25%, 50%, 75%, 100%, and 120%). The output data from ETAP were then analyzed using an indirect approach through thermal mathematical modeling based on the international electrical standards IEEE C57.91 and IEC 60076-7.

The simulation results show an exponential correlation between load and power losses. At a 25% load, the measured power loss is minimal at 0.9 kW with a voltage drop of 0.93%. However, under a 120% overload condition, power losses spike drastically to 21.0 kW with the voltage drop reaching 4.66%. The power loss deviation of 45.8% from its nominal condition acts as an early indicator of thermal anomalies. Based on the thermal model calculation analysis, these extreme power losses are proven to trigger a rise in the winding's hot-spot temperature, reaching 131.33 °C. Temperatures exceeding this design standard limit cause the insulation aging rate (Factor of Accelerated Aging) to occur 7.89 times faster, and trigger a Loss of Life of 23.67 hours for every 3 hours of overload condition. In conclusion, overloading is mathematically proven to accelerate insulation degradation due to high thermal stress; therefore, the operation of the transformer at such a marginal point is strongly discouraged.

Keywords: ETAP 19.0.1, IEC 60076-7, Voltage Drop, Power Loss, Hot-Spot Temperature, 1 MVA Transformer.