ACTUAL MAXIMUM CYCLIC CAPACITY OF INDIVIDUAL TRANSFORMERS

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ABSTRACT

One aspect of the operation of a transformer that may be of particular interest to the owner is the upper loading limit or the amount of Power (in MVA) the transformer can supply within safe operation limits (in terms of aging rate or risk of failure). If new load is being proposed there may be situations where the firm capacity of the substation is reached when the load on the substation equals the combined capacity of the transformers when one is out of service. If the capacity of the transformers can be shown to be above the nameplate rating or the rating given by loading guides then it may be possible to defer substation reinforcement. Also, it would be advantageous to be able to generate reliable data regarding the upper loading limits of transformers to support everyday network management decisions, both in terms of short-term outages and planning for future load growth.

BACKGROUND

EA Technology has developed a system for creating an accurate thermodynamic model of a large transformer that could be used to extrapolate increased ratings whilst remaining within safe thermodynamic limits. This system is based on monitoring a number of transformer parameters such as the winding temperature, voltage, load current, external ambient temperature, the operation of the fans and pumps and wind speed whilst monitoring is taking place. These parameters are logged before being downloaded back to “base” via a GPRS data link.

The hot-spot temperature as indicated by the winding temperature indicator (WTI) was monitored by installing a LVDT (linear variable differential transducer) attached to the pointer mechanism. A number of measurement transformers are installed to monitor the various currents (including fans and pumps) along with a voltage transducer installed to monitor the voltage. Finally, a weather station is situated installed within the substation compound to measure wind speed and ambient temperature.

TRANSFORMER HOTSPOT MEASUREMENT

The operation of transformers in service is controlled by the Winding Temperature Indicator (WTI). The WTI calls the fans and pumps to operate once a specified temperature has been exceeded and if the temperature continues to rise then the WTI will operate an alarm and finally disconnect the transformer by tripping the protective circuit breakers.

Before a transformer is energised the exact hot-spot inside the windings cannot accurately be predicted (because it depends on so many factors) or its location can even change over time due to movement of the winding or sludging for instance. Therefore, the WTI can only ever provide a simulation of the winding hot-spot. There are a number of different types of WTI and their construction is described in EN 50216-11:2007. The WTI is calibrated during factory heat run tests but in practice it has been found that most winding temperature indicators are out of calibration and their readings can be quite misleading. Therefore, calibration of the WTI is essential before any analysis is undertaken.

THE MODEL

The main purpose of the software is to create a model of the behaviour of the WTI. This was done by recognising that the measured WTI depends on changes in load, ambient temperature and cooling and then developing an equation that could be solved and used to simulate the WTI response for various theoretical values of load. This would enable a prediction to be made of the thermal performance of the transformer based on increased loading to establish the upper limit. One of the many advantages of this approach is that it does not rely on any prior knowledge of the transformer or its internal construction, so it can be widely applied. The output from the model is an extrapolation of MVA capacity of the transformer to winding hot-spot temperatures of;

98°C, the alarm level
100°C, the upper limit for unity ageing
120°C, the trip level

The model that was eventually developed is based on a first order ordinary differential equation (ODE) which is simply an equation that describes the rate of change of a dependent variable with respect to some other independent variable. In this case, the independent variable is time and the dependent variable is the winding temperature. The ODE represents a generalized thermodynamic equation that applies to any large mass of copper, steel, paper and oil (a transformer) and it has a number of coefficients that are modified to allow the equation to be applied to specific designs of transformers where different factors will apply to a different extent based on the individual design of each installation.
The initial values for the coefficients are calculated by the Transformer Thermal Rating Programme and are unique for each transformer based on the monitored data. The Programme then solves the ODE and calculates a value for the change in temperature with time assuming that the change in temperature is constant over the entire time increment. If, as we assume, the change in temperature is constant over the time increment, solving this equation will give a new temperature $T_1$ which is equal to the change in temperature multiplied by the time increment. This process is then repeated for the next time increment, $\Delta T_2$ and repeated again and again for subsequent time intervals to find $\Delta T_3$, $\Delta T_4$ and $\Delta T_5$ etc and our calculated (or simulated WTI) curve is generated.

The second part of the process is to solve the ODE to ascertain the WTI response for different values of load, ambient temperature and wind speed which enables the MVA load to be calculated based on the upper temperature limits as described earlier, alarm (98°C), unity ageing (100°C) and trip (120°C).

**HARDWARE**

It was decided from the outset that the system should be wireless, combining short range de-licensed radio with GSM based remote monitoring equipment to reduce the amount of time required to install (figure 1).

The overall system architecture is based on a substation occupying an area several hundred metres with up to two transformers, a weather station and a remote building containing metering and control. From each of these locations analogue signals are gathered by a “Slave Hub” and reported to a central point on site (the “Master Hub”) from which the data can be communicated over the GSM mobile phone network to a server. The data is then accessed via the internet for analysis.

**Master Hub**

The PLC in the Master Hub controls all communications by polling the 4 outstations as described and then issuing data text strings (the monitored data) to a GSM based PC telemetry device. The collected data is then transferred using GSM/GPRS (the mobile phone network) every hour to a host server. The data is then accessed over a secure internet connection and the data file containing the monitored data is downloaded to a local PC as a csv (comma separated values) text file for analysis by the Transformer Thermal Rating Programme.

**Slave Hub**

Each Slave Hub has a number of inputs that can accept either 0 to 5Vdc or 4 to 20mAdc inputs. The inputs can accept signals from a range of transducers and sensors and the signals are applied directly to the input card of a programmable logic controller. One of the advantages of using the PLC was that it was possible to have a very high sample rate (once per second) for each monitored parameter but to programme the PLC to average the data over one minute. The PLC used at each Slave Hub is “polling” once per minute by another PLC in the Master Hub which acted as the central data point. The PLC’s were connected via a Low-Power UHF Multi-Channel Radio Transceiver which operates in the 458 MHz de-licensed range under the requirements of the R&TTE Directive 1995/5/EC.

**REPLACEMENT SOFTWARE**

Once the monitored data csv file is downloaded from the secure server, the revised Transformer Thermal Rating Programme is used to create the Thermodynamic Model and generate the upper loading limits.

When the programme is initiated the first step is to start a new “project” that allows the basic parameters to be set. The default settings assign the transformer alarm and trip temperatures to typical 98°C and 120°C but the values can be changed to suit a particular application. The date and substation name can also be entered and the project is saved. This is the individual session that analyses the data.
and produces the report. The next step is to import the basic csv data file to be analysed and the minimum data to be imported must comprise:

- **Time Stamp**
- **Wind Speed in m/s**
- **Load Current in Amps**
- **Winding Temperature in °C**
- **Ambient Temperature in °C**
- **Voltage in kV**
- **Cooling 1 (on) or 0 (off)**

This data is shown in Figure 2.

Once the data is imported, the Programme is instructed to calculate the unique coefficients based on the monitored data as described previously. The programme achieves this by a series of steps that results in a unique thermodynamic model based on the unique data for each transformer. When this stage is complete, the Programme outputs are generated and the output tables are displayed showing the permissible upper loading at the range of ambient temperatures at a presumed wind speed of 0m/s. The output values and simulated data can be read directly from the Transformer Thermal Rating Programme or can be exported to Excel for further manipulation.

Figure 3 shows a comparison of monitored and predicted winding temperature. The blue curve shows the monitored data and the pink curve shows the simulated winding temperature generated by assigning the unique coefficient values and then solving the equation.
CONCLUSIONS

A computer model or computer simulation is defined as a computer program that attempts to simulate an abstract model of a particular system and computer simulations have become a useful part of modeling many natural and artificial systems. Computer simulation and modeling has its roots in the growth of computers during the 1950’s and 1960’s and has found many applications in a huge range of different industries.

The system allows the user to gain insight into the upper limits of transformer loading and should enable an assessment of large transformer safe loading limits in an easy and efficient manner.

The motivation for undertaking this project was the concern regarding the increasing population of older transformers and a recognition that more information was required from the existing population to assist with planning and asset renewal decisions. This concern is as pressing as ever in 2009 and it is hoped that the system can be widely used to develop greater confidence in the results and to build up a bank of experience over time.