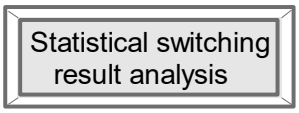
Statistical Switching Result Analysis



Henry Gras, 10/22/2020 12:25 PM

1 Introduction

This device is an option device helping to process results of statistical simulation where random is applied to switching closing times. It provides parameters which are required to apply insulation coordination standard such as IEC 60071 and IEEE Std 1313.2.

2 Get started

A statistical simulation must be performed prior to starting the analysis. The 'Save both min and max values for all scope variables' must be enable in the Statistical Option device before starting the statistical simulation.

To start the analysis, double-click on the device.

The tool will analysis all Node Voltage scope of the statistical result file. If no Voltage scope (1 pin) devices are included in the design, the analysis cannot be started.
For each scope, the tool returns:

- **The Max simulated voltage**: The voltage with the maximum absolute value which was reached during all statistical simulations for this scope.
- **Simulation number**: Number of the statistical run where the maximum voltage was reached for this scope.
  This run may be replayed using the Fixed Random Data option device.
- **Max statistical voltage** U_T: Maximum voltage estimated with the parameters of the overvoltage statistical distribution.
  $$U_T = E2 + 3\sigma$$
  In IEEE, this is called the truncated overvoltage.
- **E2**: Overvoltage with 2% chance of being exceed in the maximum voltage statistical distribution of the statistical simulation results. This value is obtained using a cumulative distribution function of the maximum voltages obtained at each statistical run.
- **Mean**: Mean of the overvoltage statistical distribution of the current statistical simulation results. The mean is defined as:
  $$\mu = \frac{\sum |Vmax_i|}{N}$$
  Where $Vmax_i$ is the maximum voltage obtained at each statistical run for this scope and N is the total number of statistical runs.
- **Standard deviation** σ: Standard deviation of the overvoltage statistical distribution of the current statistical simulation results. The standard deviation is defined as:
  $$\mu = \frac{\sum (\mu - Vmax_i)^2}{N - 1}$$

Where $Vmax_i$ is the maximum voltage obtained at each statistical run for this scope, N is the total number of statistical runs and μ is the mean.

For 3-phase voltage scopes, in addition to the analysis performed on each phase, one is done on the 3-phase combined. The statistical parameters are calculated based on the maximum voltages obtained on the 3 phases at each statistical run.
If the 'Case-Peak Method' of the insulation coordination procedure is applied, the 3-phase combined statistical parameters should be used.
If the 'Phase-Peak Method' of the insulation coordination procedure is applied, the statistical parameters of each phase should be used independently. The rate of failures of each phase must then be combined to obtain the 3-phase rate of failure.

3 Rate of failure determination

3.1 Definition

- IEEE definition of external (self-restoring) insulation: insulation which, after a short time, completely recovers its insulating properties after a disruptive discharge during test.
  For such insulation, the number of disruptive discharges tolerated is related to a specified withstand probability.
  Therefore, for external insulation, the **BSL** (Basic Switching Level) is defined as the voltage having a 10% probability of leading to a flashover (90% probability of withstand)
  Another important parameter for external insulation is the **CFO** (Critical Flashover Overvoltage) which is the voltage having a 50% probability of leading to a flashover.

- IEEE definition of internal (non-self-restoring) insulation: insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge during test.
  For internal insulation, the **BSL** (Basic Switching Level) is defined as the voltage having a 100% probability of leading to a flashover or a damage if overpassed.
  As a rule of thumb, for low voltage application, the BSL may be assumed 85% of the BIL (Basic Insulation Level)

3.2 Analysis

3.2.1 Scopes monitoring the voltage of an internal insulation

For scopes monitoring the voltage of an internal insulation, enter the BSL value and leave CFO blank. Because the BSL for such insulation is defined as a 100% probability of failure, the rate of failure is not calculated. Instead, the BSL must be larger than the Max simulated Voltage and the Max statistical voltage considering all application coefficients:

- safety coefficient: typical values in IEC 60071-2 or IEEE Std 1313.2-1999.
  For internal insulation: 15%
  For external insulation: 5%
- Coordination Factor
- etc.

3.2.2 Scopes monitoring the voltage of an external insulation

The tool will assume the scope is monitoring the voltage of an external insulation if both the BSL and CFO parameters are provided.
The CFO must be greater than the BSL.
The method to determine the Rate of Failure (R) is the one defined in IEC standard:

$$R = \int_{CFO-4Z}^{U_T} f(U)P(U)$$

Where:

- $f(U)$ is the probability density of overvoltage. **Peaks other than the highest one are disregarded, which may lead to error.**

$$f(U) = \frac{e^{-\frac{1}{2}\left(\frac{U-\mu}{\sigma}\right)^2}}{\sigma\sqrt{2\pi}}$$

  with:
  - μ: Mean of simulated overvoltage distribution
  - σ : Standard deviation of simulated overvoltage distribution
  - U_T: Maximum statistical overvoltage
- $P(U)$ is the probability of flashover of the insulation under an impulse of value U

$$P(U) = 1 - 0.5^{\left(1+\frac{\frac{U-CFO}{Z}}{4}\right)^5}$$

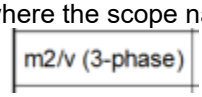
  With:
  - Z: standard deviation of insulator withstand voltage distribution
    Z: is estimated as:

$$Z = \frac{CFO - BSL}{1.3}$$

    This approximation may lead to error in the rate of failure determination.

The IEEE standard does not consider the truncation $CFO - 4Z$. For typical cases, this may lead to an underestimation of risk of less than 0.01%.

For three-phase devices, and when following the 'Phase-Peak Method' of the insulation coordination procedure, the total risk of failure is the summation of the ones of each phase.
When following the 'Case-Peak Method' of the insulation coordination procedure, the total risk of failure is the one displayed on the line where the scope name appears with (3-phase):



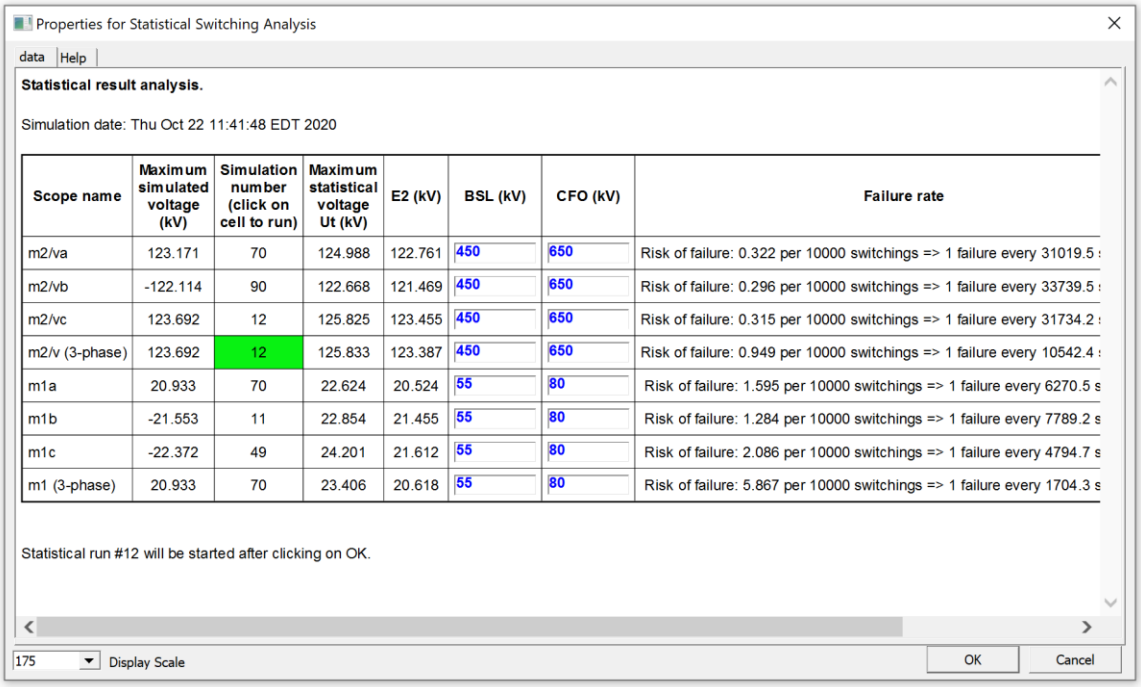
4 Files created during analysis

During the result analysis, MPLOT is used to process the results and several files are created.
Users must ensure files with same names are not being used already.
All these files are saved in the project file (folder which has the same name as the design with the extension _pj and which is located in the same folder of the EMTP design).
Once the process is completed, these files may be deleted by users.
The files are:

- **filedata_switchingOptions.txt**: MPLOT scripting file.
- **MinMax_switchingOptions.txt**: ASCII file with the simulation numbers and the min max value of each Node Voltage scope.
- **MinMax_switchingOptions_labels.txt**: labels of the scopes of the previous file.
- **t_stat_switchingOptions.txt**: ASCII file with the simulation numbers and the switching times of switches which had Random data defined during the statistical simulation and which had the scopes Random switching times enabled.
- **t_stat_switchingOptions_labels.txt**: labels of the scopes of the previous file
- **FixedRandomData_switchingOptions.dat**: This file is the one used by the Fixed Random Data device to run a user specified run number.

5 Run a specific case

Once the analysis is performed and the device mask is open, a specific statistical run number may be selected by clicking on it:



Once a simulation number is selected, click on OK.
A Fixed Random Data device will be added to start this simulation and then immediately remove.
All other Fixed Random Data devices have to be removed.