

Statistical Options

Base case + Statistical case



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1 Introduction

This device is used to setup a Statistical Analysis case. A Statistical Analysis case is a Random Data case solved in the time-domain. Instead of performing only one time-domain simulation after optional steady-state solution, EMTP performs several time-domain simulations. Each simulation has a different set of data for some devices in the design. Random device data is generated using a random function or any other data variation method. Each simulation saves minimum and maximum values for requested scopes. Saved statistical data can be visualized from the plot processor package MPLOT (options library).

For a given design *mydesign.ecf*, EMTP creates two files:

- ❑ *mydesignms.m*: ASCII plot file for providing content information on the related binary file. This file is overwritten at each EMTP run of a set of statistical simulations. This file must be selected from MPLOT for visualizing statistical data. MPLOT also provides options for automatic selections.
- ❑ *mydesigns.mda*: Binary file associated to *mydesignms.m*. Contains statistical simulation data (min and max scopes) in binary format.

Statistical analysis simulations are called random data simulations or random simulations. Devices with a Random data tab are random data devices, also called random data based devices.

A simulation without “Statistical Options” is called a standard simulation (no random data).

In the current version of EMTP only one device, the “Ideal switch” from the switches library has a Random data tab. This is a random time data based device since its random functions are used to randomize switch opening or closing times. It is however intended to extend the statistical options of EMTP and EMTPWorks to other devices and to use other types of random data in future versions of EMTP-EMTPWorks. That is why the following sections are kept generic.

2 Rules

The “Statistical Options” device can be only dragged into the top circuit. It cannot be used from a subcircuit. It is not allowed to have more than one “Statistical Options” device in the top circuit.

The Random device data tabs are enabled only when a “Statistical Options” device is available in the top circuit and turned on.

If the “Statistical Options” device is turned on, but there are no random data devices, then EMTP will stop with an error message since it is not feasible to perform statistical simulations.

3 Parameters

3.1 Study Options

This tab selects the main parameters of the statistical study.

3.1.1 Study type

The **Study type** parameter can select:

- No random data (standard simulation): This selection turns off the statistical analysis option and reverts to a standard simulation without random data.
- Statistical: Turns on the statistical simulations.
- Statistical with base case: This option is similar to “Statistical”, the only difference is that before entering the statistical simulations loop, EMTP performs a base case simulation. The base case data settings for each random data device are specified in the help section of the device. Such a simulation can be used to establish some base values in scopes or to create a reference simulation.

3.1.2 Time of dice roll

The **Time of dice roll** option is used to specify the solution time-point before which no random time event can occur. This means that the computations up to a time t_{dice} are the same for all simulations and it is only after t_{dice} that random events can start to occur and modify the simulation results.

Generally speaking, a random event must occur after t_{dice} and before the maximum simulation time t_{max} . Some conditions must be given to determine the boundaries of random data. If random data events still occur outside this interval, then they will not contribute into statistical samples. The user must verify device based selections in relation with t_{dice} and t_{max} .

The main objective in the calculation of t_{dice} is to save computer time, since EMTP saves a snapshot file at t_{dice} and restarts all simulations from t_{dice} .

- The **Computer defined** option requests EMTP to calculate t_{dice} after scanning all random data devices and determining the minimum time before which no changes can occur in the network solution for all possible random simulations. This calculation is based on the input field “Maximum multiple of standard deviation” (K_{σ}).
- The **User defined** option is for manual specification of t_{dice} . This time is verified in EMTP using the same procedure as above and overridden if necessary. EMTP will send messages into the log file (see “Input Output files” option) for selected t_{dice} .

3.1.3 Number of simulations

The **Number of simulations** ($N_{\text{simulations}}$) indicates the maximum number of statistical simulations to be performed. Random data is generated at each simulation and the complete simulation is performed starting from t_{dice} .

When a statistical analysis case has devices with systematic random data, then the number of systematic combinations $N_{\text{simulations}}^{\text{sys}}$ may be higher than $N_{\text{simulations}}$. The **Do all systematic combinations** checkbox is used to override $N_{\text{simulations}}$ by $N_{\text{simulations}}^{\text{sys}}$ when $N_{\text{simulations}}^{\text{sys}} > N_{\text{simulations}}$.

It is allowed to conduct a simulation where devices with Gaussian and/or Uniform statistical laws (non systematic) coexist with devices with systematic laws. The following situation can occur:

- If $N_{\text{simulations}} > N_{\text{simulations}}^{\text{sys}}$ and non systematic law devices exist, then EMTP performs $N_{\text{simulations}}^{\text{sys}}$ simulations with random data calculated from Gaussian and/or Uniform laws at each systematic simulation. The systematic simulations are reset after $N_{\text{simulations}}^{\text{sys}}$ and restarted till all $N_{\text{simulations}}$ are completed.

3.1.4 Seed for random numbers

This field has two options: Pre-defined and Random. When Pre-defined is used, then running the same case twice will give the same results for all simulations since the same sequence of random numbers will be generated. This option can be mostly used for testing. When Random is used, then each rerun of $N_{\text{simulations}}$ will outcome into a different result for each simulation.

3.1.5 Maximum multiple of standard deviation (K_{σ})

This option is used in the calculation of t_{dice} explained above. It is also used in sending messages into the log file when some devices are suspected to have random data occurrence outside the interval $[t_{\text{dice}}, t_{\text{max}}]$.

The user can also request to limit device random numbers by clicking on the **Enforce** checkbox. In this case the Gaussian law based numbers are limited by

$$[\mu_j - K_{\sigma}\sigma_j, \mu_j + K_{\sigma}\sigma_j]$$

where μ is the mean and σ is the standard deviation of a given device j . It is noticed that this will impact on the resulting distribution.

3.1.6 Special delay for “Ideal switch” devices

This option is only applicable to the “Ideal switch” from the switches library.

It generates an additional random time to be added to all random data switches of type “Ideal switch”. There are 3 options. The delay can be added only to random closing switches (closing delay), to random opening switches (opening delay) or both (closing and opening delay).

The delay T_{offset} is calculated as follows:

$$T_{\text{offset}} = k\alpha(D_{\text{max}} - D_{\text{min}}) + kD_{\text{min}}$$

where k is $1/f/360$ (f being the Frequency) and α is a random number which is uniformly distributed over the unit interval $[0, 1]$. D_{min} and D_{max} are the maximum and minimum angles in degrees which define a window of a sine wave having the frequency f in Hz, from which the added time is randomly selected according to a uniform distribution. When $D_{\text{max}} < D_{\text{min}}$, EMTP automatically replaces the window by 360° .

It is allowed to send T_{offset} to its scope T_{offset} found in the scope group sw_{offset} .

3.2 Output (Post-processing options)

The post-processing options are related to the saved information in the scopes. In this version of EMTP all requested scopes are saved for their statistical data. The saved data is the maximum and the minimum value

for each simulation for each scope. There are also random data scopes available from random data based devices.

The available options are:

- ❑ **Save all simulation waveforms:** This option is available to save not only statistical data, but the entire time-domain waveforms for each simulation as in a standard non-statistical case. It is only provided for testing and should be used with **Extreme** care, since a very large number of files may result. There will be one main plot file and one related binary file for each simulation.
- ❑ **Save min and max time-points for all scope variables:** This option allows saving the occurrence time of min and max in addition to the actual min and max values. Only the absolute max times will be saved if the option below is not checked.
- ❑ **Save both min and max values for all scope variables:** If this option is not checked, EMTP saves only the absolute max for each scope. If this option is selected, then both the max and min will be made available. The absolute max can be calculated in MPLLOT (options.clf) from the available max and min.

4 Example

This example is intended to demonstrate available features and available manipulations of statistical data. Its diagram is presented in Figure 1. The selected parameters are not necessarily practical, since the objective here is to demonstrate available options through a simple example.

There are two random data switches in this design. The first 1-phase switch SW_FAULT uses a random Uniform function with a mean $\mu_{SW_FAULT} = 16\text{ms}$ and a standard deviation of $\sigma_{SW_FAULT} = 5\text{ms}$. The 3-phase switch SW1 should open after a delay in reference to SW_FAULT. The delay is given a Gaussian law with $\mu_{SW1a} = 28\text{ms}$ and $\sigma_{SW1a} = 4\text{ms}$. The phases b and c are set to depend on phase a (for demonstration purposes) with a mean delay of 1ms and a standard deviation of 0.5ms.

The total number of simulations is 100. When all the simulations are completed, the user can double-click on MPLLOT and select both the “Base case simulation waveforms” and “Statistical simulation data”. The MPLLOT GUI main panel comes up and shows available selections.

The Base case presents switching time selections based on the entered mean values and accounts for delays. This is explained in the Help section of the “Ideal switch” device.

4.1 Using PLOT and CDF

The statistical set of data can be analyzed using the available plot functions. A first verification is made on the actual SW_FAULT random data. The SW_FAULT variables from the t_stat and t_stat_real groups are sent into the y-axis. This is shown in Figure 2. The PLOT function of MPLLOT is clicked to visualize that the generated random timings are occurring within the simulation interval. Since this is a closing switch, the calculated times (t_stat) and the event times (t_stat_real) must coincide when within the simulation interval (see Figure 3).

The CDF button of MPLLOT is used only on SW_FAULT@t_stat to verify the actual distribution of random data. The calculated mean and standard deviation are shown on the top of the graph (see Figure 4).

The next step verifies the random events for SW1a. The PLOT of its t_stat and t_stat_real is shown in Figure 5. Since this is an opening switch, the two timings do not coincide since actual (real) opening is occurring on current crossing zero. It can be seen that there were two cases where the switch did not open within the simulation interval.

4.2 Using HISTC

Figure 6 shows the maximum voltage samples on all 3 phases of BUS1. The scope variables BUS1a, BUS1b and BUS1c are selected in MPLLOT from the group vn_max and sent into the y-axis. The BAR button is used to

produce the shown plot. It is also feasible to produce the same plot using pu data. This can be achieved through the “Add Data fields” button of MPLOT. It is also needed to turn on pu usage (“Options” menu in MPLOT) in bar type plots.

The “Add Data fields” button operates on selections in the left hand side list of scope variable appearing in MPLOT. If the variable BUS1a is highlighted and the “Add Data fields” button is clicked, it allows entering the data shown in Figure 7. The pu section of this data panel can be used by bar type plots, but its main usage is for the HISTC function. The HISTC function demonstrated in Figure 8, provides a histogram count for BUS1a@vn.

The entered data fields can be saved using (“File>Save>User data fields”) and reloaded for a subsequent MPLOT session, using the “Load Data fields” button. There is only one data fields file per design.

It is noticed that HISTC can combine several files on the same plot, which can be used to visualize data from separate runs of the same statistical case. The following steps can be applied for the presented case stat_case.ecf:

- 1 Run a set of 100 simulations.
- 2 Go to the “EMTP>View Output File” menu and make a Copy of the Statistical Plot file giving a tag “_run1”, for example.
- 3 Run another set of 100 (or any other number) simulations.
- 4 Double-click on MPLOT and enter “_run1” in the “Extra tagged files” section. Then click OK. This will open the previous statistical plot data and the new statistical plot data files.
- 5 Select the same variables from both files and create a unique histogram count for BUS1a@vn@1 and BUS1a@vn@2.

The HISTC function of MPLOT assumes that data concatenated from different files is compatible. It also retains the last file’s edges vector for presenting its plot.

If data fields were saved from a previous usage of MPLOT they can be reloaded using the “Load Data fields” button. Since there is only one data fields file per design, the user can also click on “Load Data fields” for all shown files in the current design. This will ensure that the same edges vector and pu quantities are used in the HISTC function.

It is noticed that the second (or subsequent) set of simulations does not need to have the exact same data in the design. It can, for example, perform less simulations or change random data in devices.

It is also feasible to create a common-cumulative distribution function for empirical data from several sets of simulations. This is the task of the CCDF button.

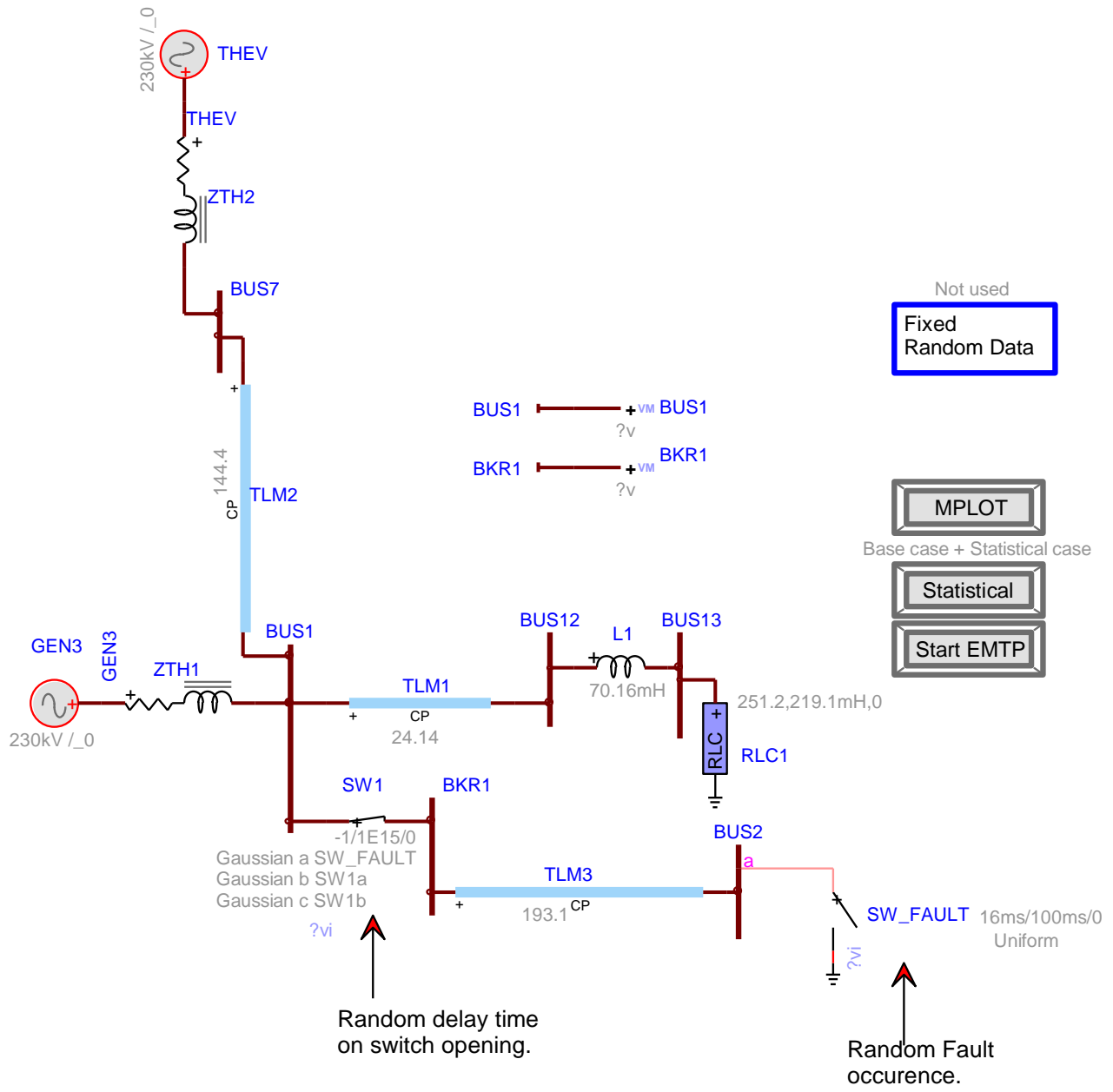


Figure 1 Statistical analysis example ([stat_case.ecf](#))

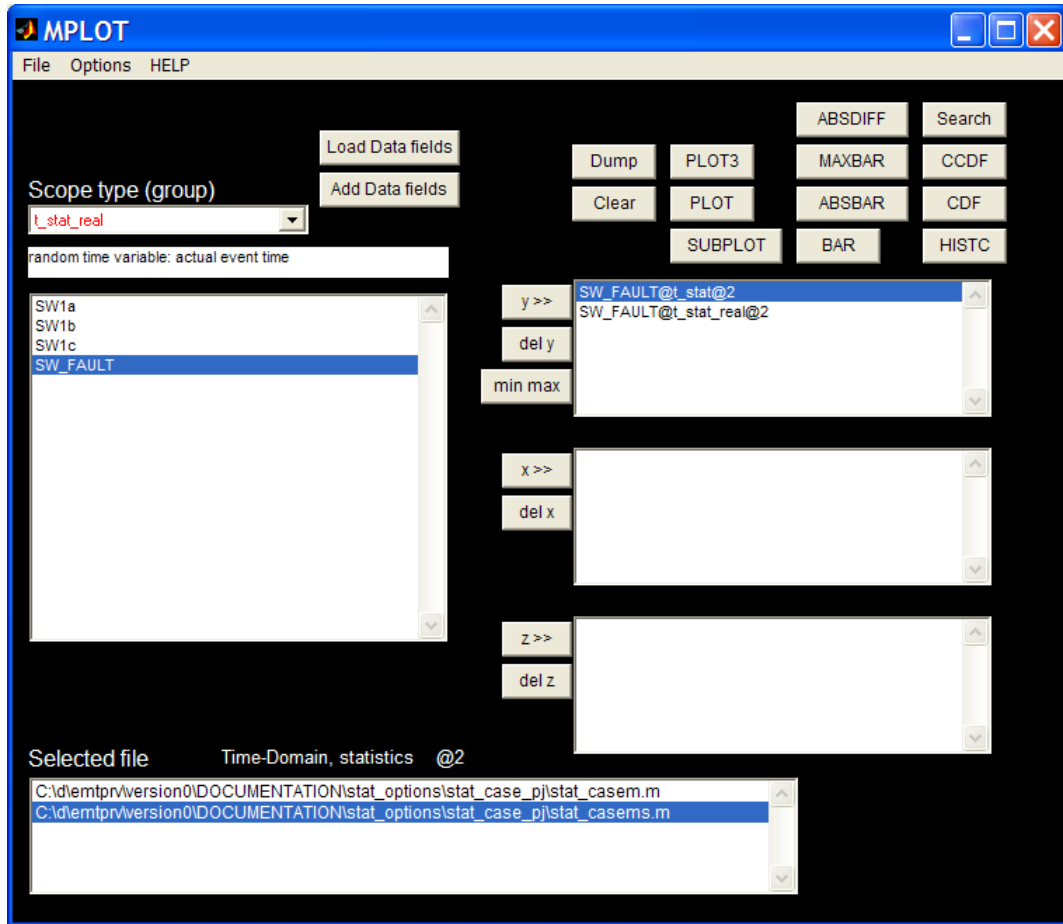


Figure 2 MPLOT main GUI with selections in y-axis

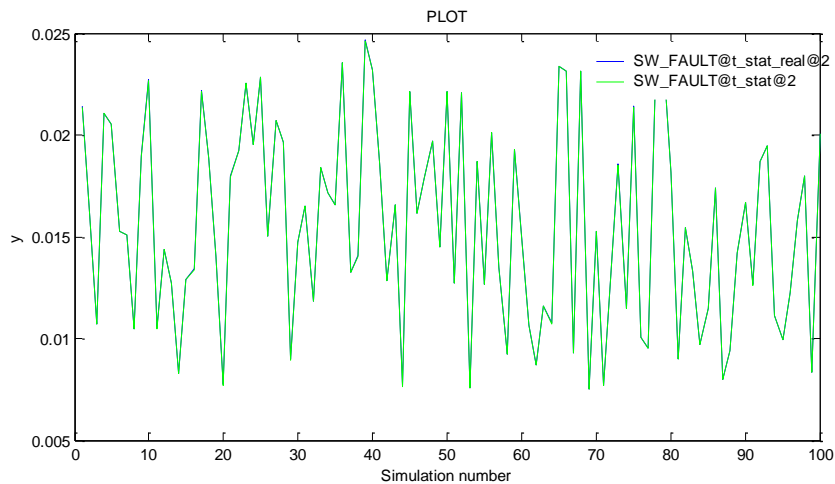


Figure 3 The random closing data for SW_FAULT

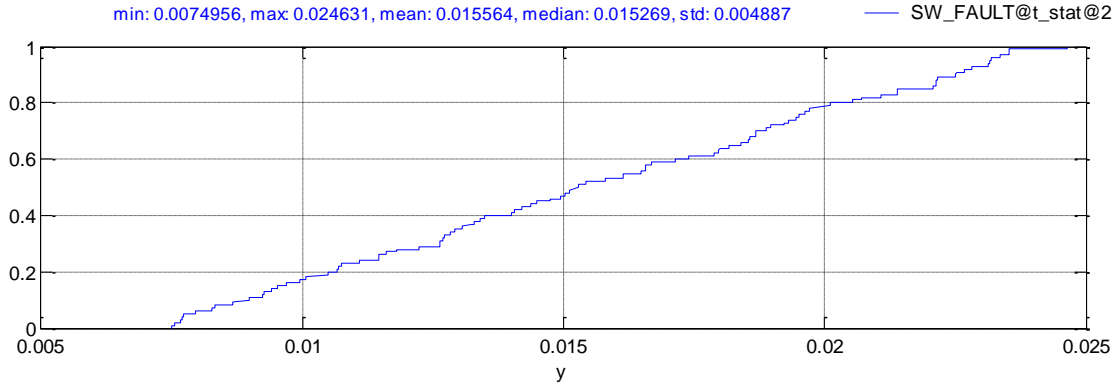


Figure 4 The cumulative distribution function for SW_FAULT closing times

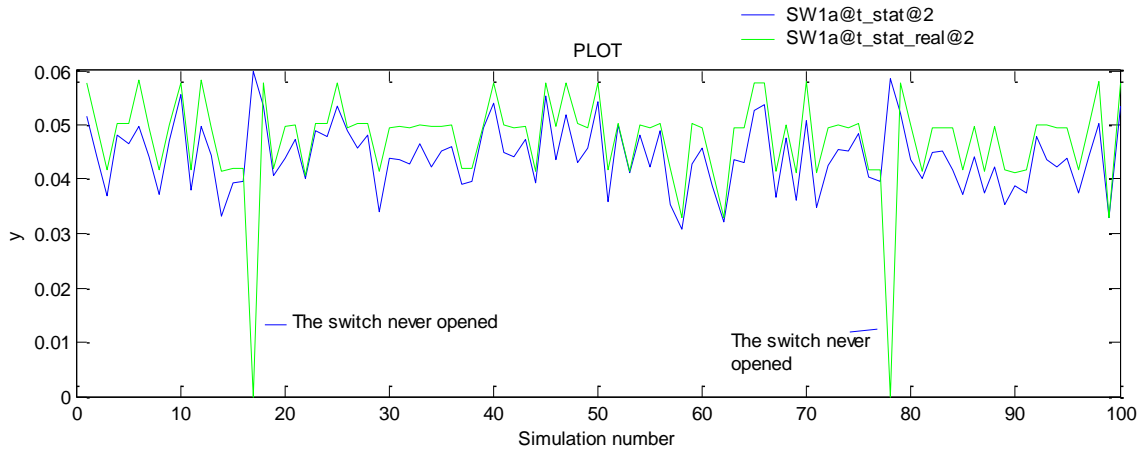


Figure 5 The random opening data for SW1a

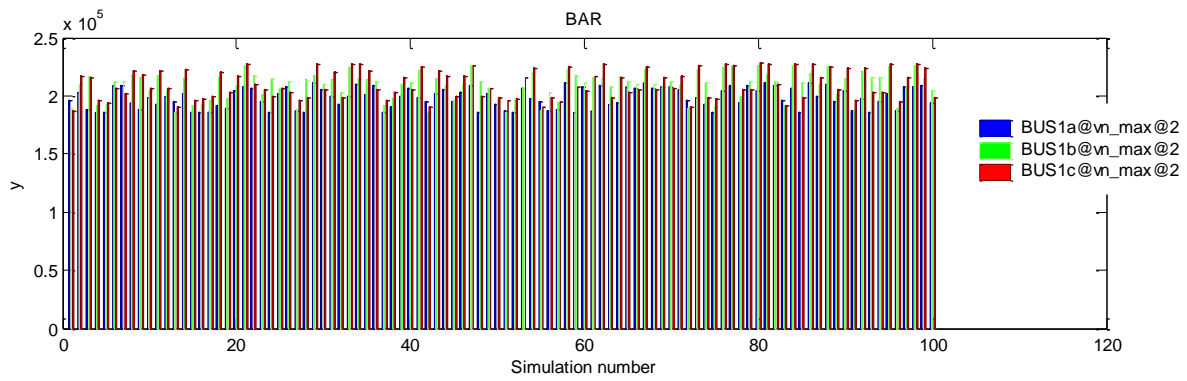


Figure 6 The maximum voltage samples at BUS1

Histogram Count Parameters

Optional tag name for identifying groups created with this variable
 BUS1@vn

pu base
 188e03

min of edges vector (pu)
 0.8

step of edges vector (pu)
 0.01

max of edges vector (pu)
 1.5

OK Cancel

Figure 7 Data fields added for BUS1a

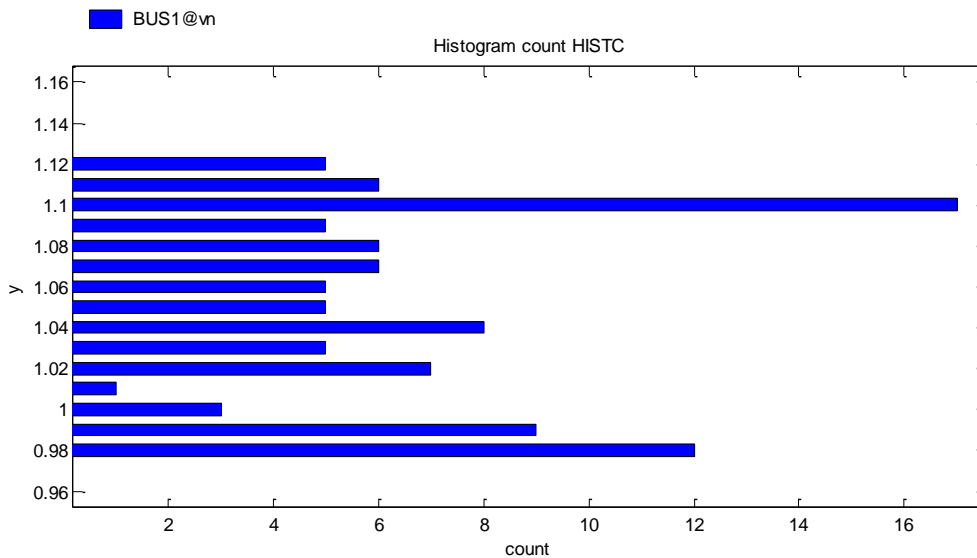


Figure 8 Histogram count function using the parameters entered in Figure 7.

4.3 Using Search

In some cases it is required to find the conditions that lead to a given observation. If, for example, the criteria is the maximum overvoltage appearing on a breaker phase, then using BAR plot and zooming allows finding the simulation leading to the worst overvoltage. This is demonstrated in Figure 9. It appears that the simulation 38 gives the highest overvoltage and it appears on phase b.

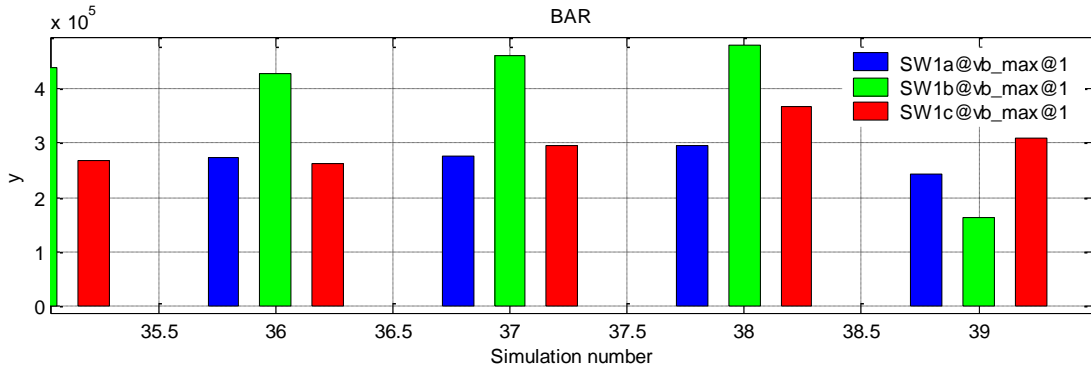


Figure 9 Zooming to find the worst overvoltage simulation number

Another approach is to search with a given range. This is achieved using the Search button in MPlot. In the case of SW1 overvoltages, a search for voltages near 400kV with a 20% tolerance, gives the Figure 10. This plot can be also used with the zoom function to locate simulation numbers.

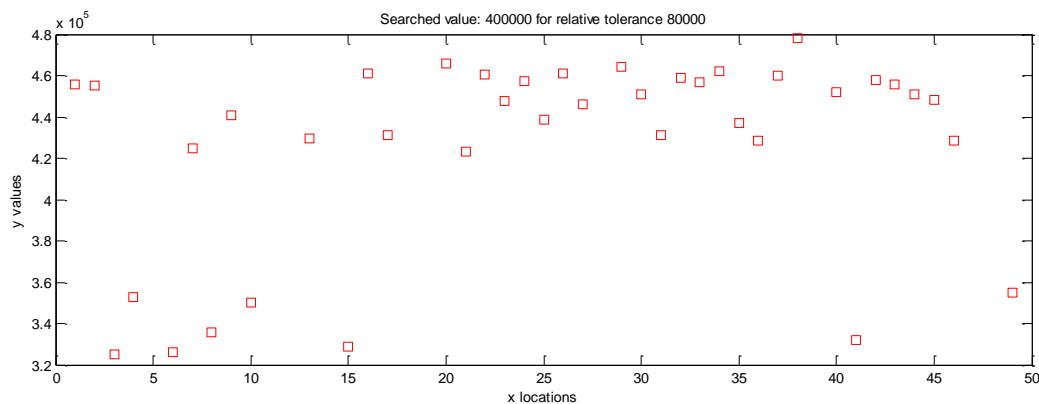


Figure 10 Search function usage on SW1 voltages

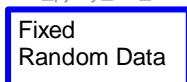
4.4 Reproducing (replaying) simulations

Once the desired simulation number has been located, it may be useful to visualize the complete time-domain waveforms of that simulation. This can be achieved by sending the desired random variables into the y-axis and selecting the MPlot menu “File>Save>Random data for devices”. The needed random variables are the network-independent variables, those generated using statistical laws, such as the random closing and opening times of the “Ideal switch”.

In the example of Figure 1 it is needed to save SW1a@t_stat, SW1b@t_stat, SW1c@t_stat and SW_FAULT@t_stat. The save menu needs the desired simulation number and an arbitrary file name to be referenced by the “Fixed Random Data” option in options.clf. In the following example the selected simulation number was 38 and the file name was: my_sw_times.dat. The “.dat” extension must be used.

The next step is to double-click on “Fixed Random Data” in Figure 1 and to select the file my_sw_times.dat. The icon of “Fixed Random Data” will change to indicate that this option is now active.

stat_case_p\my_sw_times.dat



It is not needed to delete or modify the statistical options, since EMTP will automatically assume a standard (non-statistical) simulation. The contents of my_sw_times.dat are:

```
4
SW1a
0.0362689438793152
SW1b
0.0373262656011829
SW1c
0.0387938585585494
SW_FAULT
0.0158265768133
```

There is a total of 4 devices, all switches in this case. Each switch name is followed by its closing or opening time according to selections made in the Random data tab. The user can also modify this file using an editor. The switch names must be exactly identical to those appearing in the design. If a switch name is omitted and still exists in the design with a random data selection, then EMTP will freeze the timings only for identified switches and perform a statistical simulation.