

## Normal Distribution of the Breaker Closing Time Using the Multiple-Run Component

Written for PSCAD v4.5 and v4.6.

### 1. General description of the example

The multiple-run component is developed to perform parametric studies in power system. Through selection of appropriate parameter and input settings, the user can adjust the number of simulations that will be executed (number of simulation runs). The output variable signals from this component can be used as input signals to other components.

Figure 1 shows the multiple-run component available in the Master library.

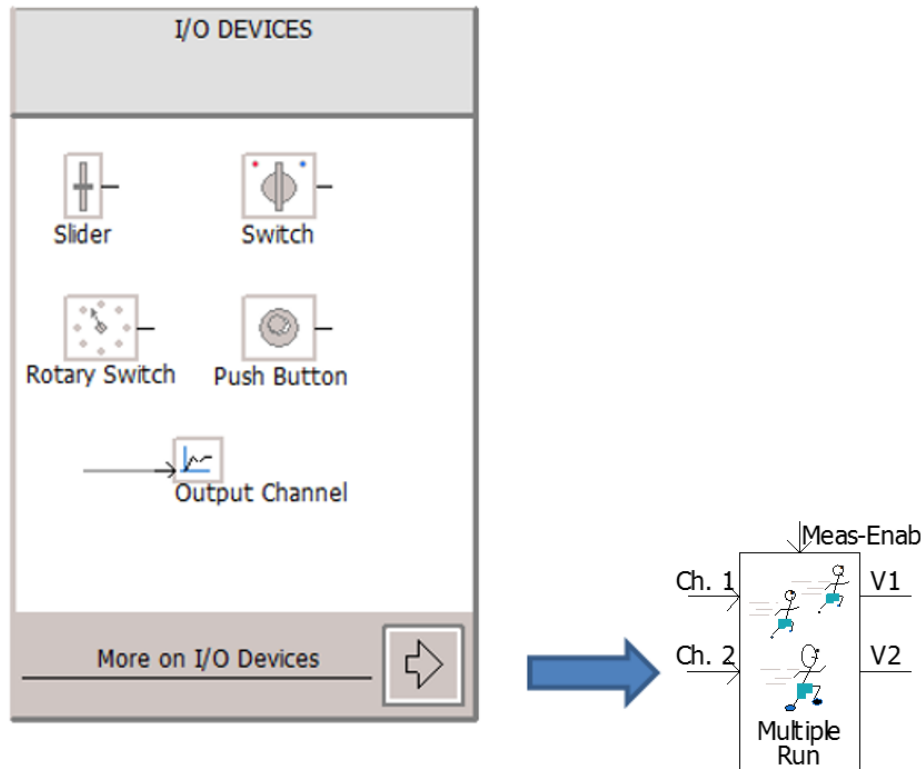


Figure 1: Multiple-run component in the Master library

## 2. Example Description

Before describing the multiple-run component, the simulation example is described first to understand the purpose of the settings for the component in the next section.

As shown in Figure 2, this example illustrates a simple point on wave (POW) study for a transformer energization. This will demonstrate the capabilities of the multiple-run component to discover the worst case scenario (maximum inrush current) when the closing time (BRK1) of the breaker changes from one run to another.

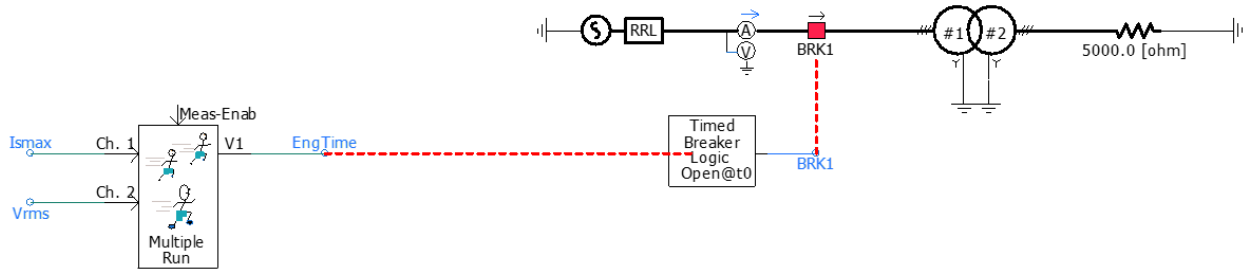


Figure 2: The Multiple-run component is used to change the closing time of the breaker to obtain the POW where the maximum inrush current occurs

At the end of this demonstration, we will discover on which point-on-wave the maximum inrush current occurs.

Similar application examples for the multiple-run component are as follows:

- Changing the point on wave (POW) of a fault inception, in order to find the worst overvoltage and/or peak fault current.
- Modifying the gains of a controller, in order to find the best response following a disturbance.
- Stepping through a range of RLC or system parameters to determine an optimum.
- Changing the type and location of faults, as well as the POW, in order to find worst case voltage and current transients.
- POW switching of a transmission line or cable, in order to determine the worst case transient overvoltage levels at different locations on the line.

## 3. Multiple-run Component Settings

As shown in Figure 2, the multiple-run component has variables (V1 and V2), recording channels (Ch. 1 and Ch. 2) and an enabling signal (Meas-Enab) that are discussed as follows:

1. **V1 and V2:** Variables steered by the component.

The variables can be used as inputs to only variable-type parameters on any other component. Depending on the requirements, the user can select up to six variables (V1 to V6). However, only one of the variables can be changed between two successive simulation runs.

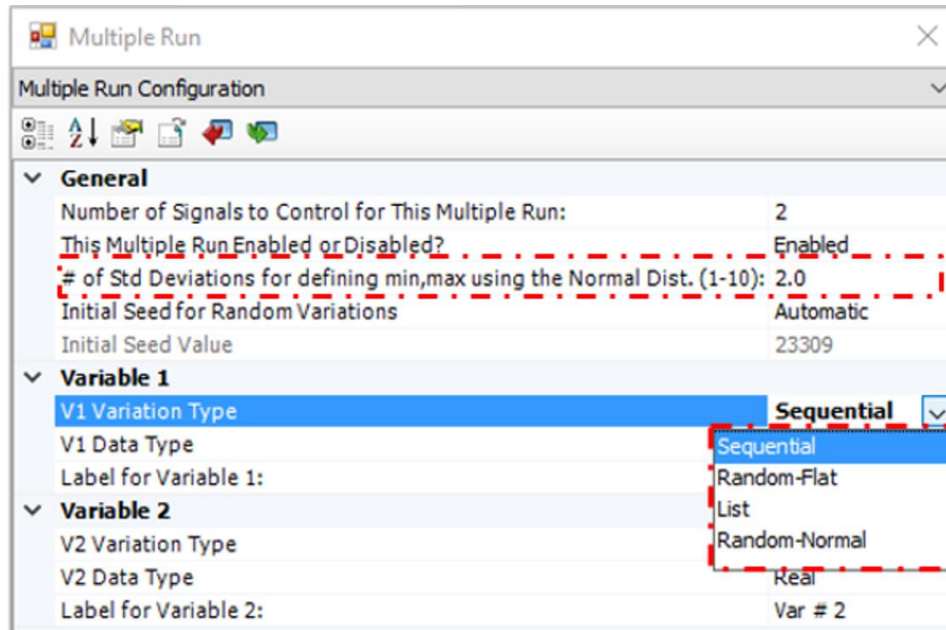


Figure 3: Settings for Variables in the multiple-run component

Variation Type:

Variables can be set for the multiple-run component in the following ways:

- **Sequential:** The variable value between successive runs will be incremented by a fixed value. The user will define the first (start) and last (end) values, and the increment.

Example: If the output required is 0.1, 0.2, 0.3 ... 1.2 for successive runs, the input data required is:

- Start of range = 0.1
- End of range = 1.2
- Increment = 0.1

- **Random-Flat:** The variable X will be modified randomly over the specified range.

Example: If 250 output values over the range 0.0 to 1 is required for successive runs, the input data required is:

- Number of runs for this variable = 1000
- Start of range = 0.0
- End of range = 1.0

- **List:** The variable X will be modified according to the list provided. The maximum number of output values that can be assigned with this selection is 10.

Example: If values 5, 6 and 10 are the required outputs for successive runs, the input data required is:

- Number of runs for this variable (1-10) = 3
- X1 = 5.0
- X2 = 6.0
- X3 = 10.0

- **Random-Normal:** The variable X will be modified using a normal distribution (using the # of standard deviations defined in the parameter section) over the range specified.

Example: If 1000 output values over the range 0.5 to 0.516 is required for successive runs, the input data required is:

- Number of runs for this variable = 1000
- Start of range = 0.500
- End of range = 0.516

As shown in Figure 4, in this example, the energization time (EngTime) is selected as the variables of the component. Energization time (EngTime) is selected as Random-Normal for variable type and real for data type. This variable changes for 1000 times randomly in between 0.5 and 0.516 sec (one cycle).

The closing time will be a normal-random distribution.

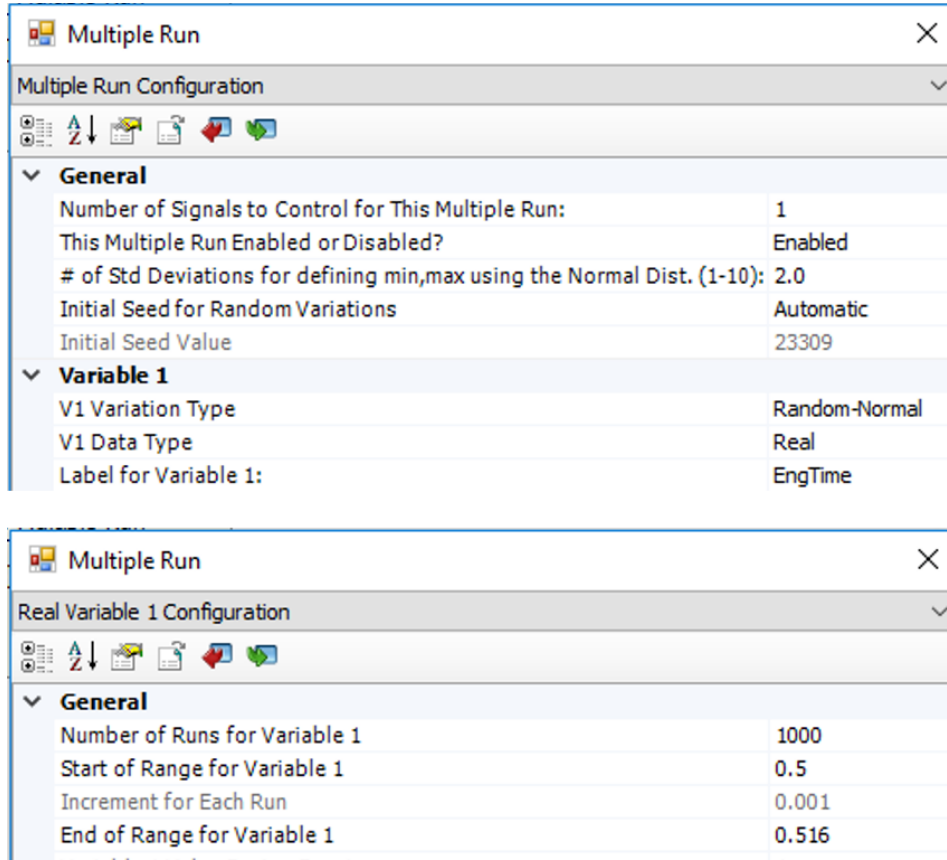


Figure 4: Settings for the multiple-run component to change the closing time of the breaker between 0.5 and 0.516 sec (randomly for 1000 times)

2. **Ch. 1 and Ch. 2:** Input signals to be recorded. These signals are recorded to an output file.

The multiple-run component includes facilities to record results from each simulation run. Up to six channel inputs (Ch. 1 to Ch. 6) are available to record signals. If more are required, the user may include the Multiple-Run Additional Recording component in the project. Each channel will record a single value per simulation run, based on the input to that channel over the recorded duration. The criteria for determining the recorded value for each channel is selected by the user. The selection can be based on one of the following criteria.

- Minimum value of the input over the recording period.
- Maximum value of the input over the recording period.
- Maximum absolute value ( $|x|$ ) of the input over the recording period.
- Integral of X squared (ISE).

The recorded values (Ch. 1 to Ch. 6) can be saved in a multiple-run output file, along with the output signals corresponding to that run. The output file name must be specified in the corresponding parameter input field of the component.

For example, Figure 5 shows that the Number of channels to Record for Each Run is 2. The recorded channels (Ch. 1 and Ch. 2) are saved in the output file named “R1.out”.

The optimal run is identified based on channel #1. In other words, this channel is specified as the channel for determining the optimum run. The optimum selection can be based on minimum (Min) or maximum (Max) criteria. In this example, it is selected based on maximum. The selected channel will be observed for each run, and the run which is determined as the optimum will be repeated after all runs are completed.

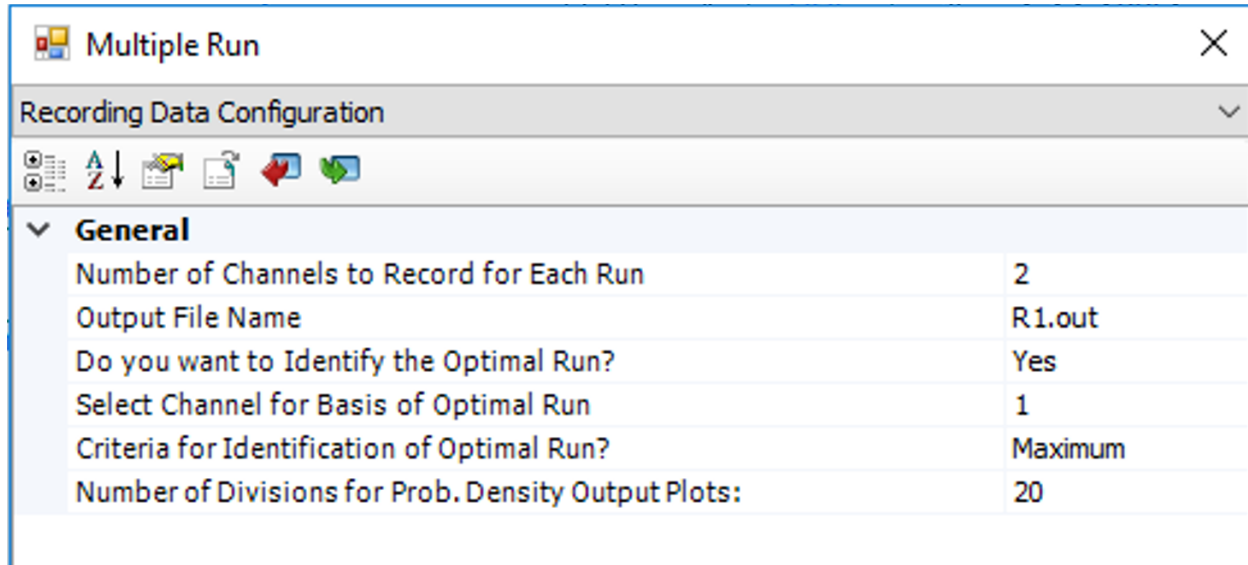


Figure 5: Recording data in the multiple-run component; the channel 1 which is maximum inrush current is selected as the criteria for the optimum run

Figure 6 shows the settings for the channels (Ch. 1 and Ch. 2). These channels connect to external signals such as:

- Maximum inrush current ( $I_{Max}$ )
- rms voltage ( $V_{rms}$ ) at the terminal of transformer

The channels can be recorded only for one certain principle (None, Minimum, Maximum, integral square error (ISE)) during each run. In this example, Maximum (|X|) and Minimum (X) criteria are used for Channel 1 and Channel 2 respectively.

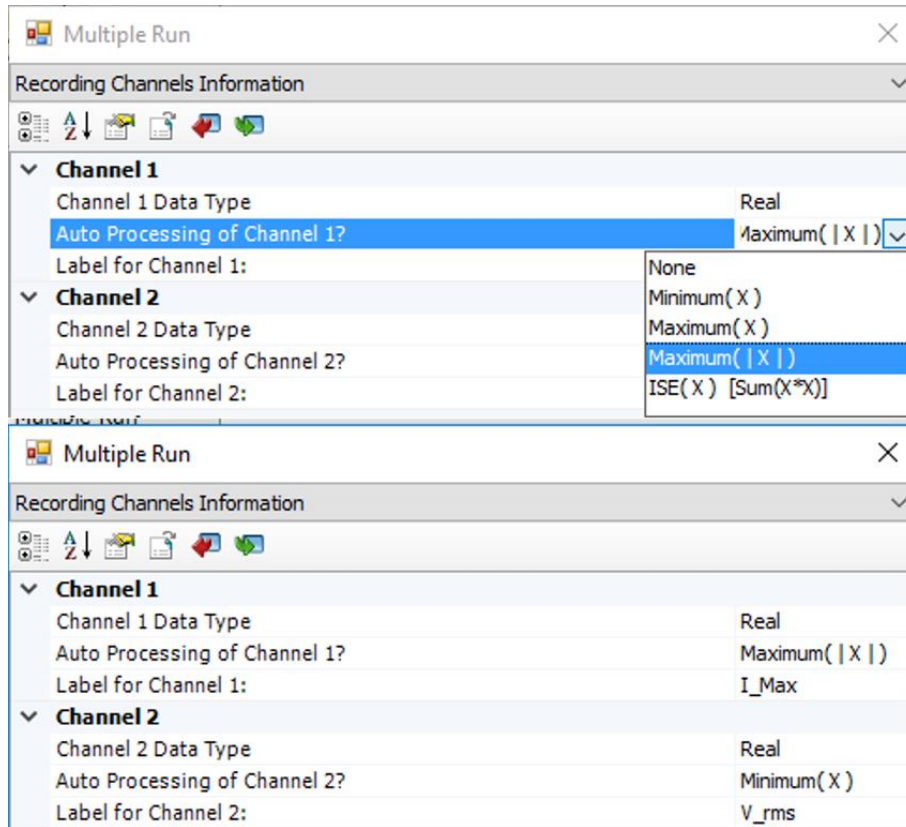


Figure 6: Recording channels in the multiple-run component.

- Meas-Enab: Used to enable (set to 1) or disable (set to 0) the channel recording. Recording will be active only when the input to this variable is 1. As shown in Figure 7, Meas-Enab is set to 1 between the lower input limit and upper input limit. The lower input limit is defined by the energization time (EngTime). The upper input limit is selected by the external signal equal to 1 sec.
- The Maximum (|X|) and Minimum (X) for the recorded channels are calculated right after energization until when the simulation time passes the upper input limit. In this example, the upper input limit is selected equal to 1 sec. If the auto-processing of the channel was selected as “None”, the channels would be recorded only at time equal to 1 sec.

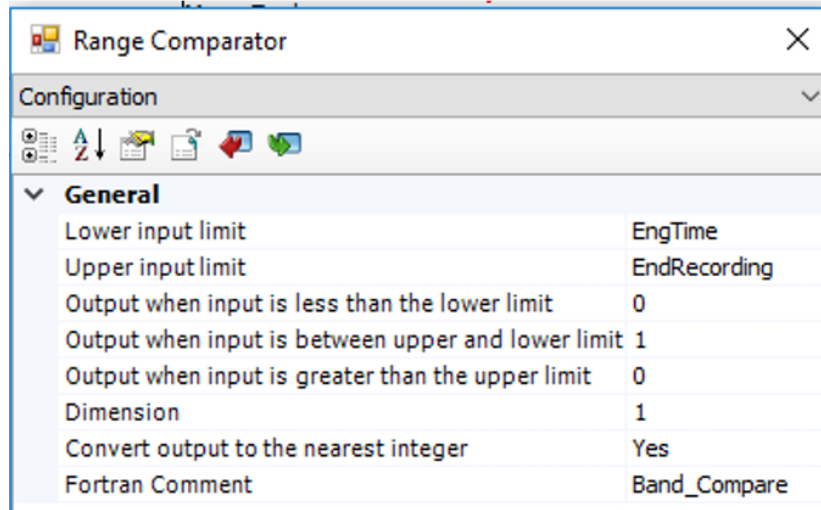
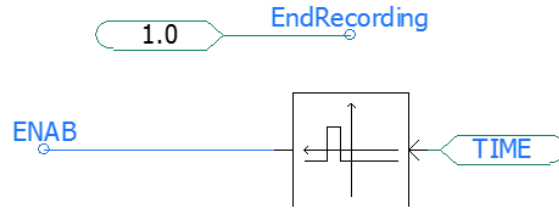


Figure 7: Meas-Enab signal is controlled externally to make sure the channels are recorded after transformer energization and before 1 sec

### Simulation results

The multiple-run component runs the simulation for 1000 times and at each time it energizes the transformer at a random point on wave. The inrush current and terminal voltage of the transformer are saved in the file at the end of each run. When the 1000 simulations are completed the component calculates the optimum run and reruns the simulation for that run to generate the results. The output file (R1.out) is available in the folder created by PSCAD.



Figure 8 shows selected runs out of 1000 runs for the normal-random energization time with recoding channels values.

Run #	EngTime	I_Max	V_rms
1	0.5081152285	1.427226832	0.9281035400
2	0.5065320486	1.515120518	0.9271629081
3	0.5028051858	1.476165381	0.9278364414
4	0.5061130344	1.525749626	0.9269115262
5	0.5108930140	1.426602608	0.9281421528
6	0.5013252518	1.471347868	0.9278833062
7	0.5120317846	1.519104479	0.9270580267
8	0.5096716924	1.472733110	0.9278783034
9	0.5118471794	1.526997124	0.9268735727
10	0.5019659990	1.320424371	0.9273028064
...			
469	0.5029158236	1.490959642	0.9275657291
470	0.5117824711	1.527386592	0.9269056218
471	0.5094996179	1.497841579	0.9274644486
...			
998	0.5092665435	1.518925528	0.9271008687
999	0.5155469073	1.407717608	0.9280163600
1000	0.5085965286	1.505364514	0.9273256938

Figure 8: Selected simulation results for the 1000 randomly-generated energization time. The maximum inrush current and rms voltage are recorded for each run

Figure 9 shows the optimum run i.e. # 470 which is obtained based on the results obtained from 1000 runs and re-runs the simulation for run # 470.

Run #	EngTime	I_Max	V_rms
1001	0.5117824711	1.527386592	0.9269056218

Figure 9: The multiple-run component selects Run#470 as the optimum run because the inrush current is maximum

Figure 10 shows the statistical summary of the recorded channels. Based on the normal distribution, the mean is calculated using the following formula:

$$\mu = \frac{1}{N} \sum_{k=1}^N x_k$$

The standard deviation is calculated using the following formula:

$$\sigma = \sqrt{\frac{1}{N} \sum_{k=1}^N (x_k - \mu)^2}$$

where N is the number of samples (x) which is 1000 in this example.

Once the mean and standard deviation are known, then the cumulative probability for 2% and 98% levels can be calculated as following formula:

$$Z(2\%) = \mu - 2.053748941152 \times \sigma$$

$$Z(98\%) = \mu + 2.053748941152 \times \sigma$$

Statistical Summary Based on 1000 Runs:

	EngTime	I_Max	V_rms
Minimum:	0.5000721355	1.288829474	0.9268627854
Maximum:	0.5159828714	1.527386592	0.9281690943
Mean:	0.5082543667	1.449698221	0.9275235189
Std Dev:	0.3548944289E-02	0.7045491466E-01	0.4078474417E-03
2% Level:	0.5009657262	1.305001515	0.9266859026
98% Level:	0.5155430073	1.594394927	0.9283611351

Figure 10: Statistical summary of the recorded channels

Figure 11 and Figure 12 show the probability density functions for channel 1 (I\_Max) and channel 2 (V\_rms) respectively.

Probability Density Functions (%) for Variable 1, I\_Max

Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.
1.294793402	2.700000000	2.700000000	97.300000000
1.306721258	2.800000000	5.500000000	94.500000000
1.318649114	2.500000000	8.000000000	92.000000000
1.330576970	2.900000000	10.900000000	89.100000000
1.342504826	2.000000000	12.900000000	87.100000000
1.354432681	2.600000000	15.500000000	84.500000000
1.366360537	2.100000000	17.600000000	82.400000000
1.378288393	3.000000000	20.600000000	79.400000000
1.390216249	3.600000000	24.200000000	75.800000000
1.402144105	3.300000000	27.500000000	72.500000000
1.414071961	3.500000000	31.000000000	69.000000000
1.425999817	4.600000000	35.600000000	64.400000000
1.437927673	3.900000000	39.500000000	60.500000000
1.449855529	4.300000000	43.800000000	56.200000000
1.461783385	4.300000000	48.100000000	51.900000000
1.473711240	6.300000000	54.400000000	45.600000000
1.485639096	6.200000000	60.600000000	39.400000000
1.497566952	7.400000000	68.000000000	32.000000000
1.509494808	10.000000000	78.000000000	22.000000000
1.521422664	22.000000000	100.000000000	0.000000000

Figure 11: The probability density functions for channel 1 (I\_Max)

Probability Density Functions (%) for Variable 2, V<sub>rms</sub>

Centre of Range	Probability(%)	Cumulative Prob.(%)	100-Cumulative Prob.
0.9268954431	6.300000000	6.300000000	93.700000000
0.9269607586	6.600000000	12.900000000	87.100000000
0.9270260740	4.200000000	17.100000000	82.900000000
0.9270913895	4.300000000	21.400000000	78.600000000
0.9271567049	2.700000000	24.100000000	75.900000000
0.9272220203	8.500000000	32.600000000	67.400000000
0.9272873358	6.000000000	38.600000000	61.400000000
0.9273526512	5.100000000	43.700000000	56.300000000
0.9274179667	3.800000000	47.500000000	52.500000000
0.9274832821	4.500000000	52.000000000	48.000000000
0.9275485976	3.800000000	55.800000000	44.200000000
0.9276139130	2.600000000	58.400000000	41.600000000
0.9276792285	3.500000000	61.900000000	38.100000000
0.9277445439	4.100000000	66.000000000	34.000000000
0.9278098594	4.700000000	70.700000000	29.300000000
0.9278751748	4.900000000	75.600000000	24.400000000
0.9279404902	3.000000000	78.600000000	21.400000000
0.9280058057	5.400000000	84.000000000	16.000000000
0.9280711211	6.900000000	90.900000000	9.100000000
0.9281364366	9.100000000	100.000000000	0.000000000

Figure 12: Probability density functions for channel 2 (V<sub>rms</sub>)

Figure 13 and Figure 14 show the graphs for the probability density functions for channel 1 (I<sub>Max</sub>) respectively.

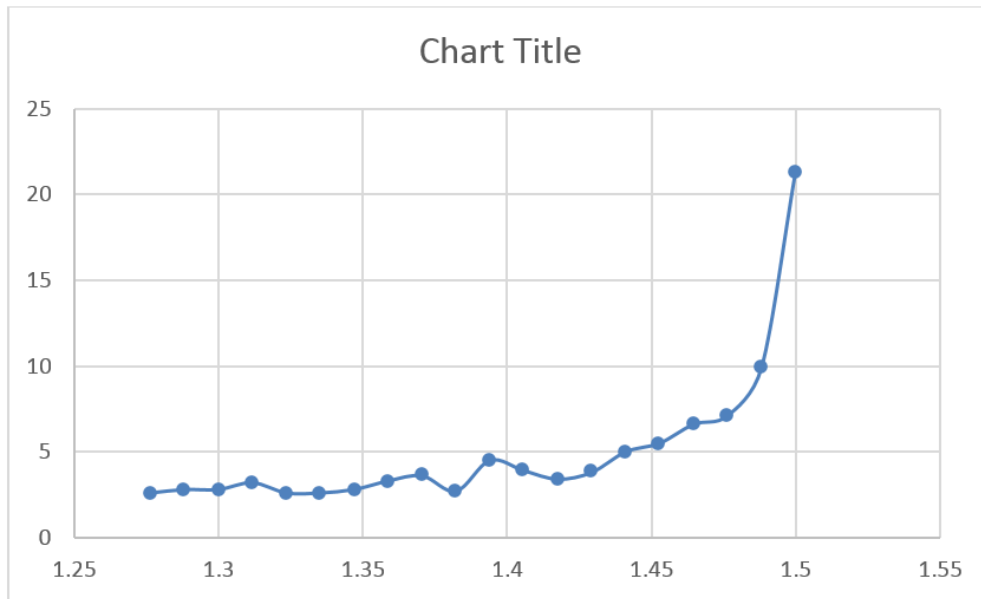


Figure 13: The probability function for recorded channel 1 (I<sub>Max</sub>)

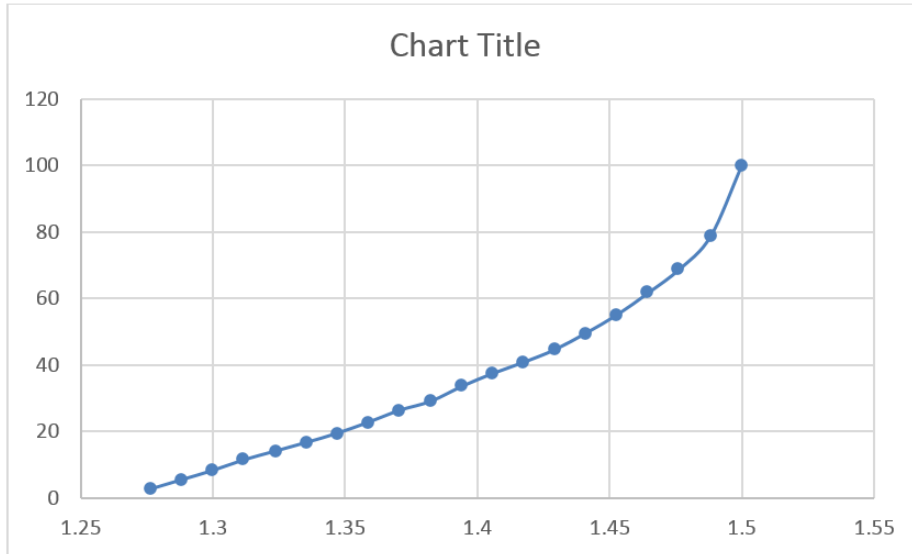


Figure 14: Cumulative probability function for recorded channel 1 (I\_Max)

**NOTE**

While the data given by the multiple-run component can be useful to determine 2% and 98% levels for system events, some due diligence is still necessary. As shown in the figures above, the probability distribution of this particular energization event is not in fact 'Normal'. This example was selected to show that even with a 'Normal' input for energization time, it is not guaranteed that the measured data will be 'Normal'. The calculation of the 2% and 98% levels are based on the assumption that the data fits the shape of a 'Normal' distribution.

### Appendix A: Recording Output Channel Component to a file

The Output Channel component for recording of output quantities can be used to save the complete time waveform (as shown in Figure 15) for each run (which can lead to a large number of output files).

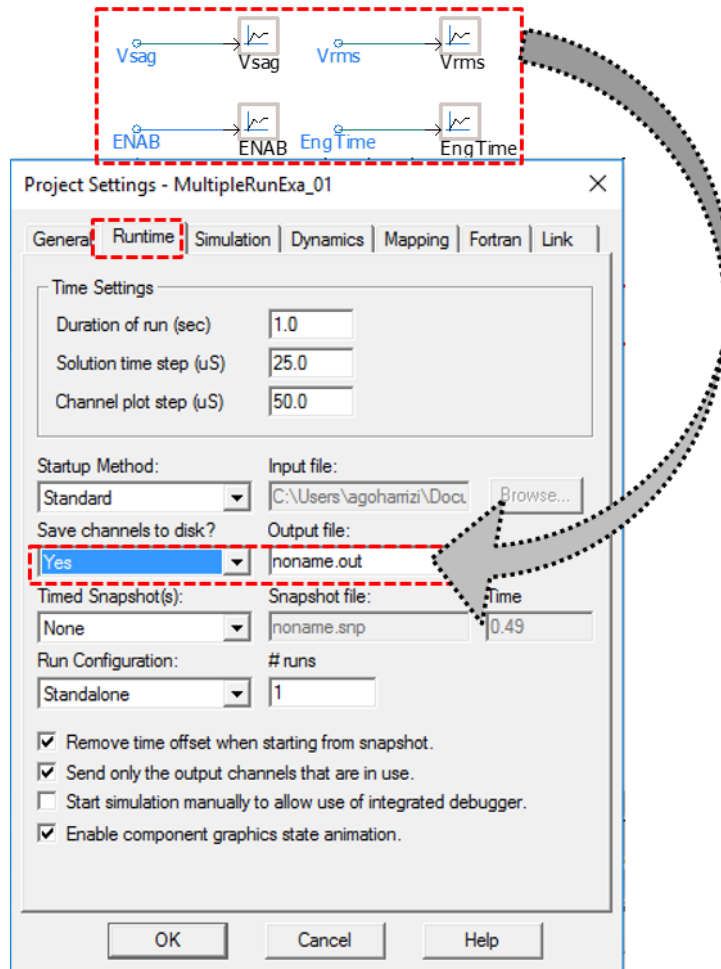


Figure 15: Alternative method to save the signals in the simulation to a file