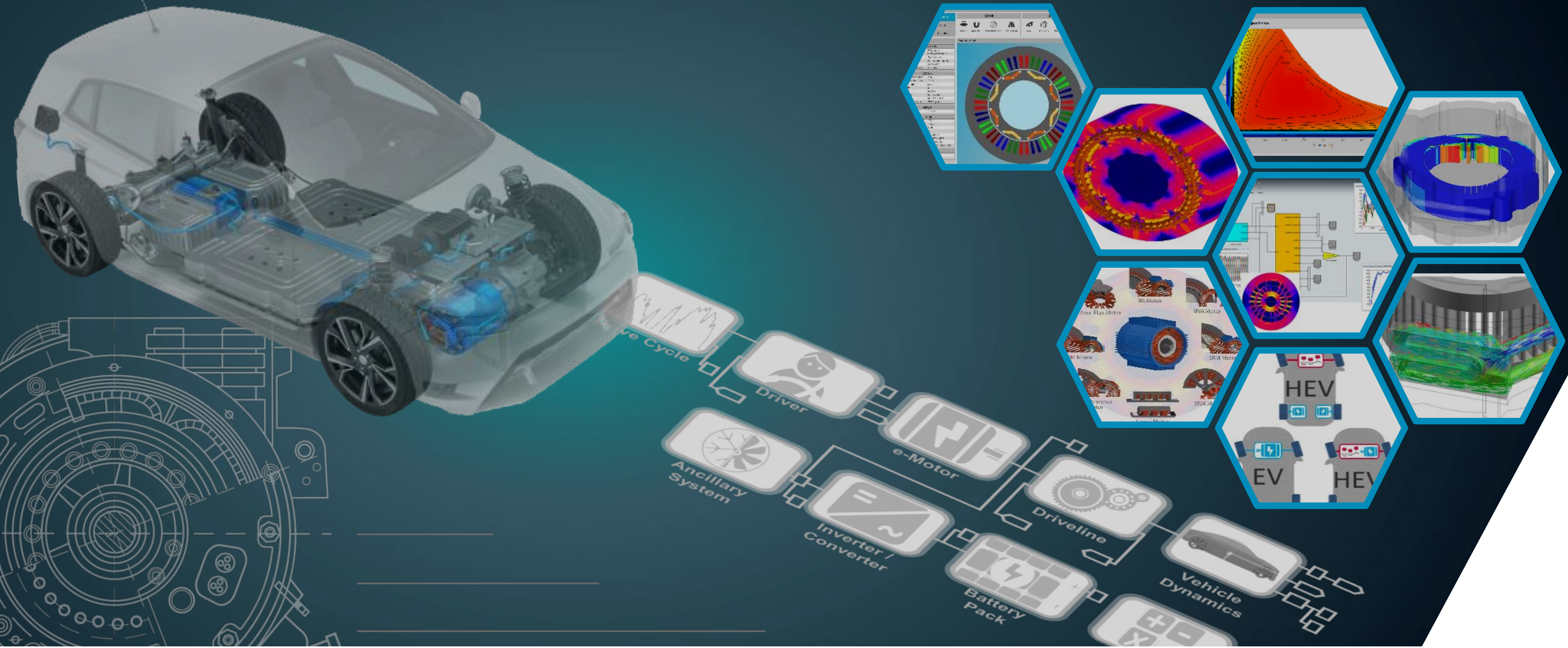



# HYPERSTUDY: MULTIDISCIPLINARY DESIGN OPTIMIZATION PROCESS

ALTAIR

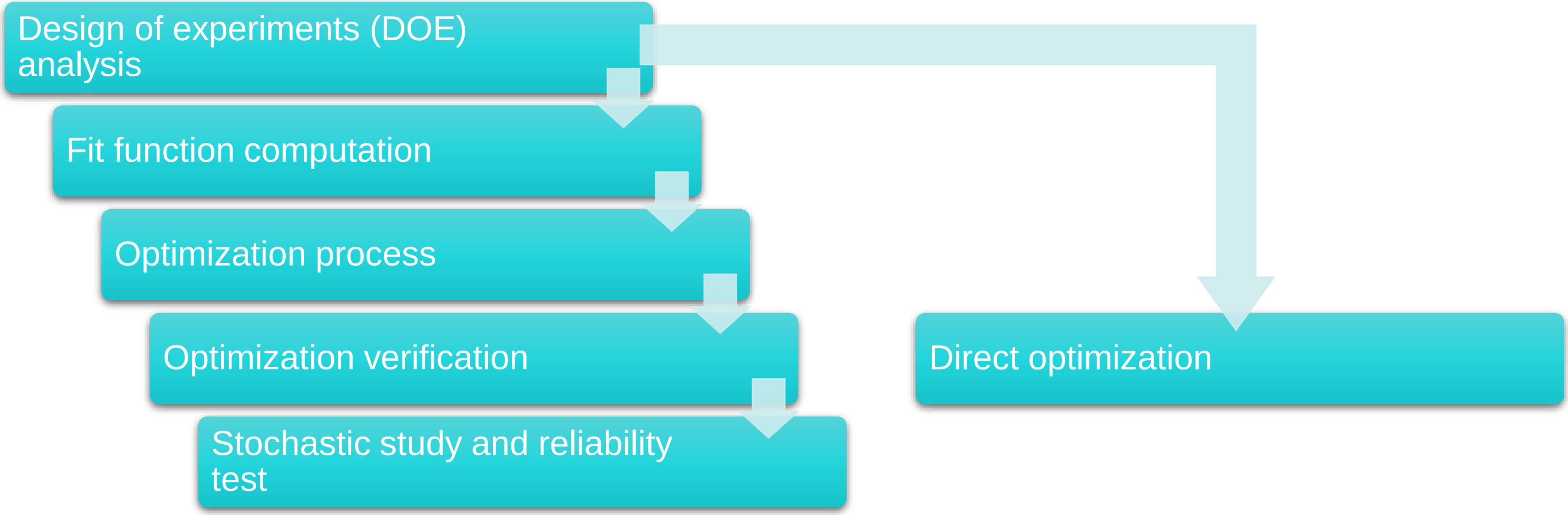
## ALTAIR MULTIDISCIPLINARY DESIGN OPTIMIZATION PLATFORM FOR ELECTRIC MOTORS

October 2021, Altair Flux / FluxMotor Valorization and Support Team

# OUTLINE

Two optimization workflow are available in HyperStudy

- Optimization based on fit functions
- Direct optimization method



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# OPTIMIZATION BASED ON FIT FUNCTIONS

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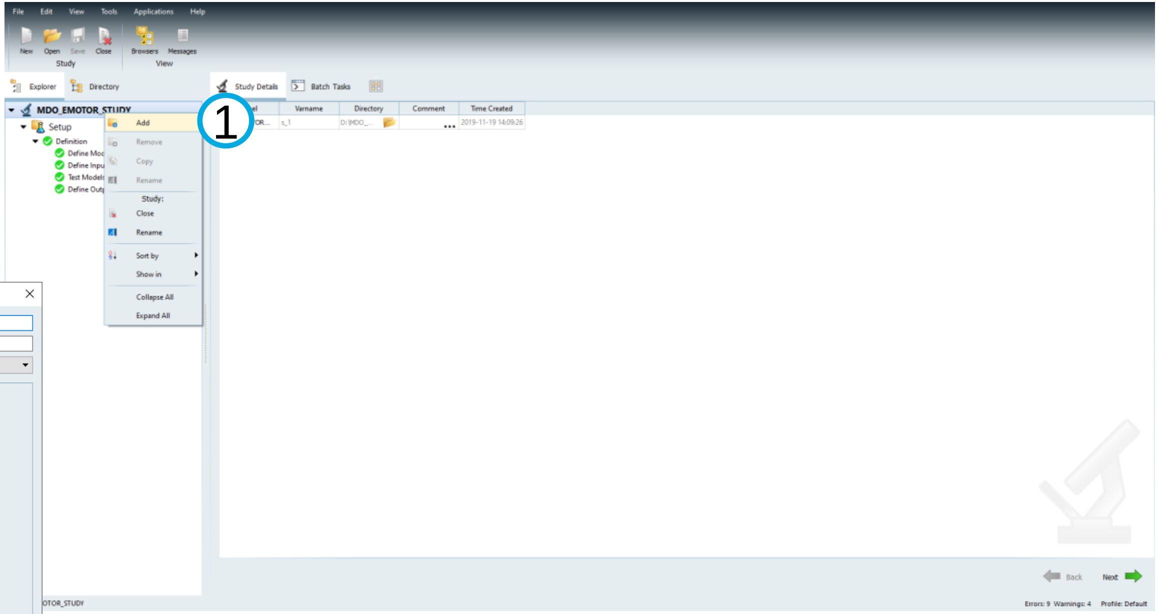
# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

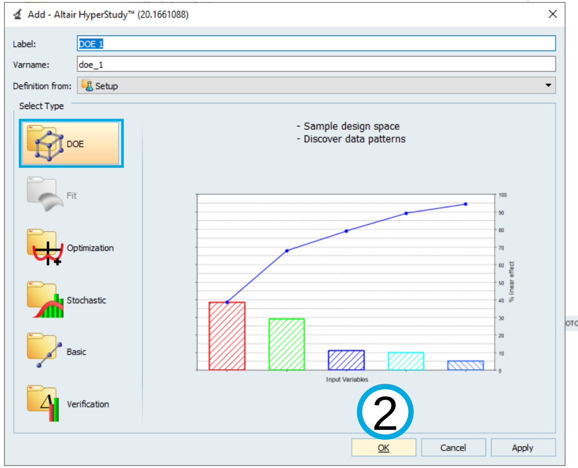
# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis initialization

- Add a new DOE analysis

| Step | Action |
|---|---|
| 1 | Right click on the project “MDO_MOTOR_STUDY”, click on [Add] |
| 2 | Select the type as “DOE”, click on [OK] |



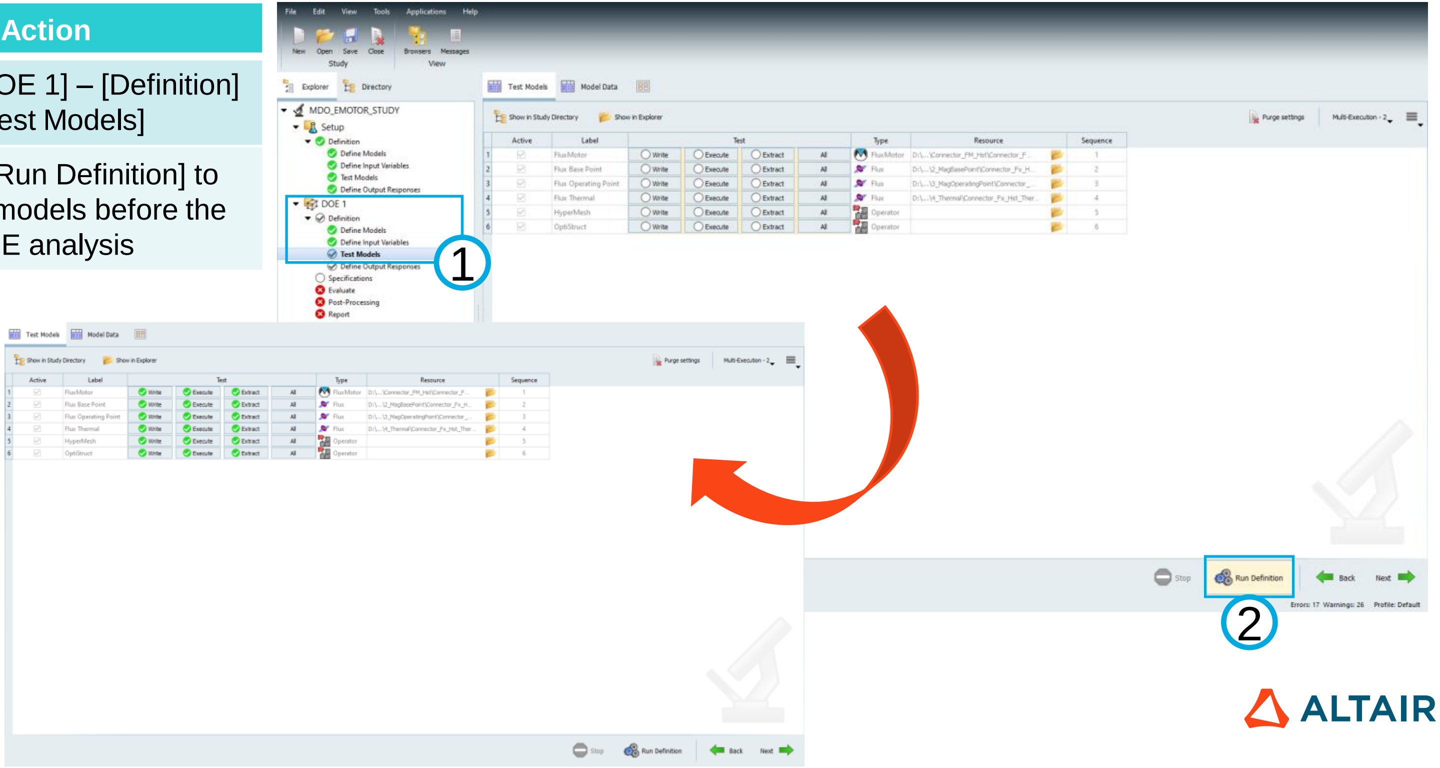



# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis initialization

- Verify model definitions

| Step | Action |
|---|---|
| 1 | Click on [DOE 1] – [Definition] – [Test Models] |
| 2 | Click on [Run Definition] to verify the models before the DOE analysis |



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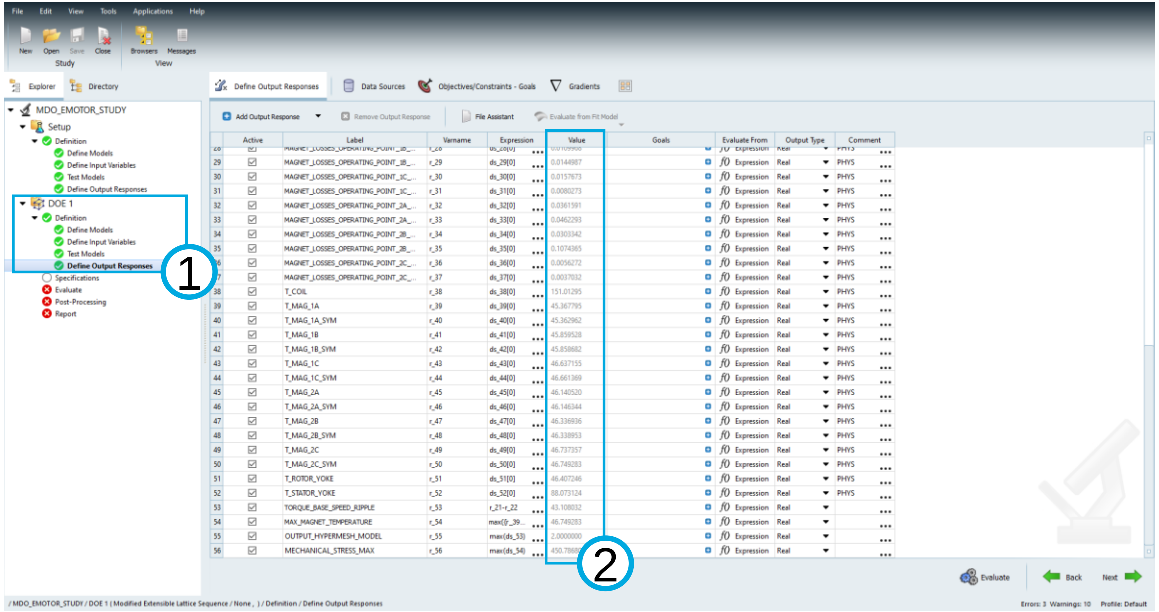
# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis initialization

- Verify output responses

| Step | Action |
|---|---|
| 1 | Click on [DOE 1] – [Definition] – [Define Output Responses] |
| 2 | Verify all the output values |



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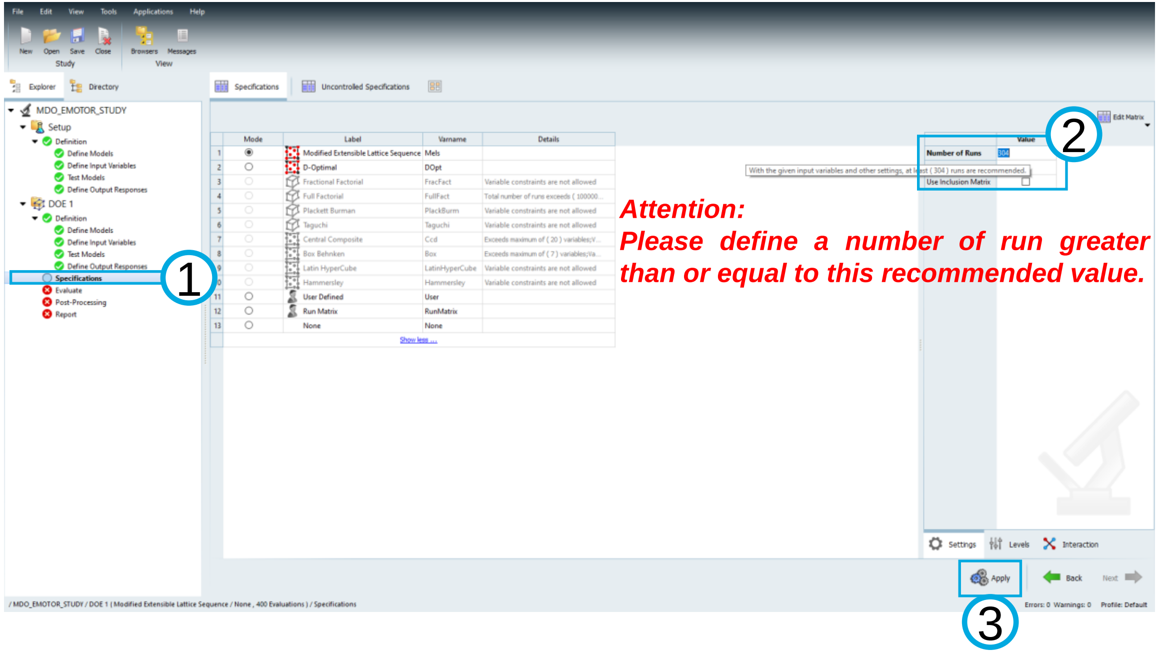
# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- Specify the DOE analysis

| Step | Action |
|---|---|
| 1 | Click on [DOE 1] – [Specification] |
| 2 | Define the “Number of Runs” for the DOE analysis |
| 3 | Click on [Apply] |




***Attention:***
***Please define a number of run greater than or equal to this recommended value.***



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# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

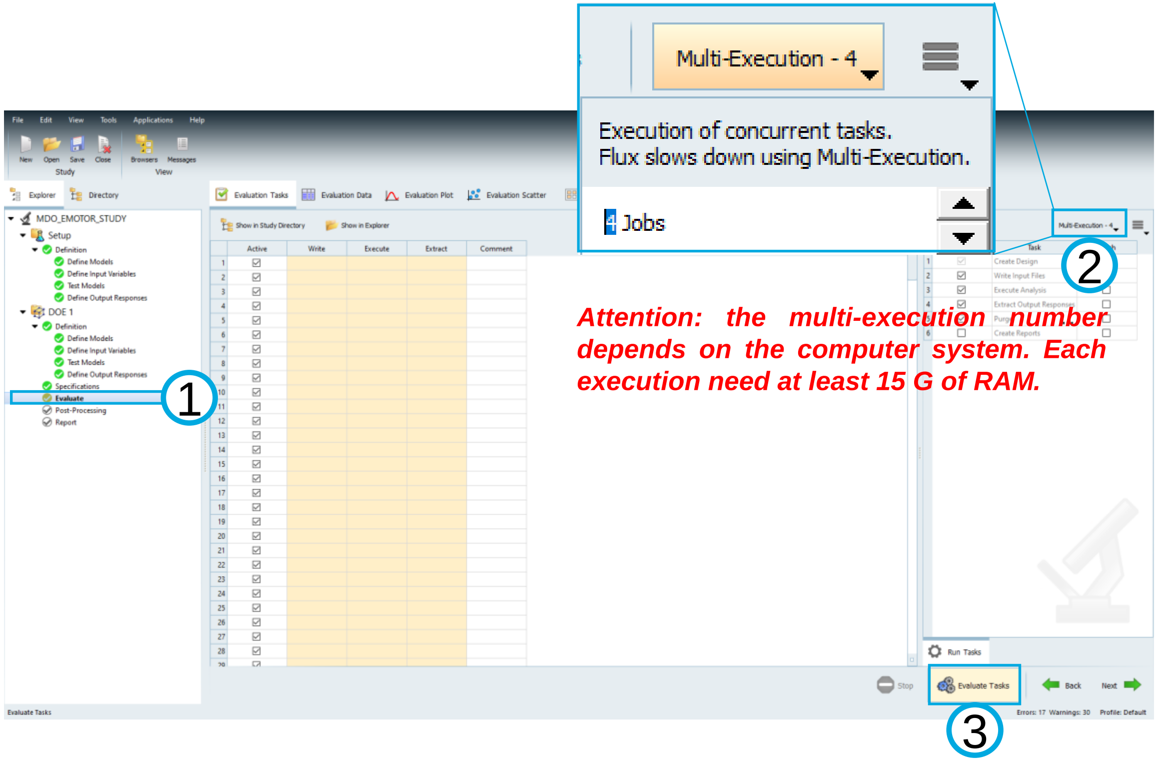
- Evaluate DOE tasks

| Step | Action |
|---|---|
| 1 | Click on [DOE 1] – [Evaluate] |
| 2 | Click on [Multi-Execution] to increase the number of parallel computation |
| 3 | Click on [Evaluate Tasks] |

*Note:*
*The project is solved in a computation server. RAM of the server is* ***192*** *Gb.*

*With the following information:*
*Number of Runs:* ***608***
*Number of multi-excution:* ***10***

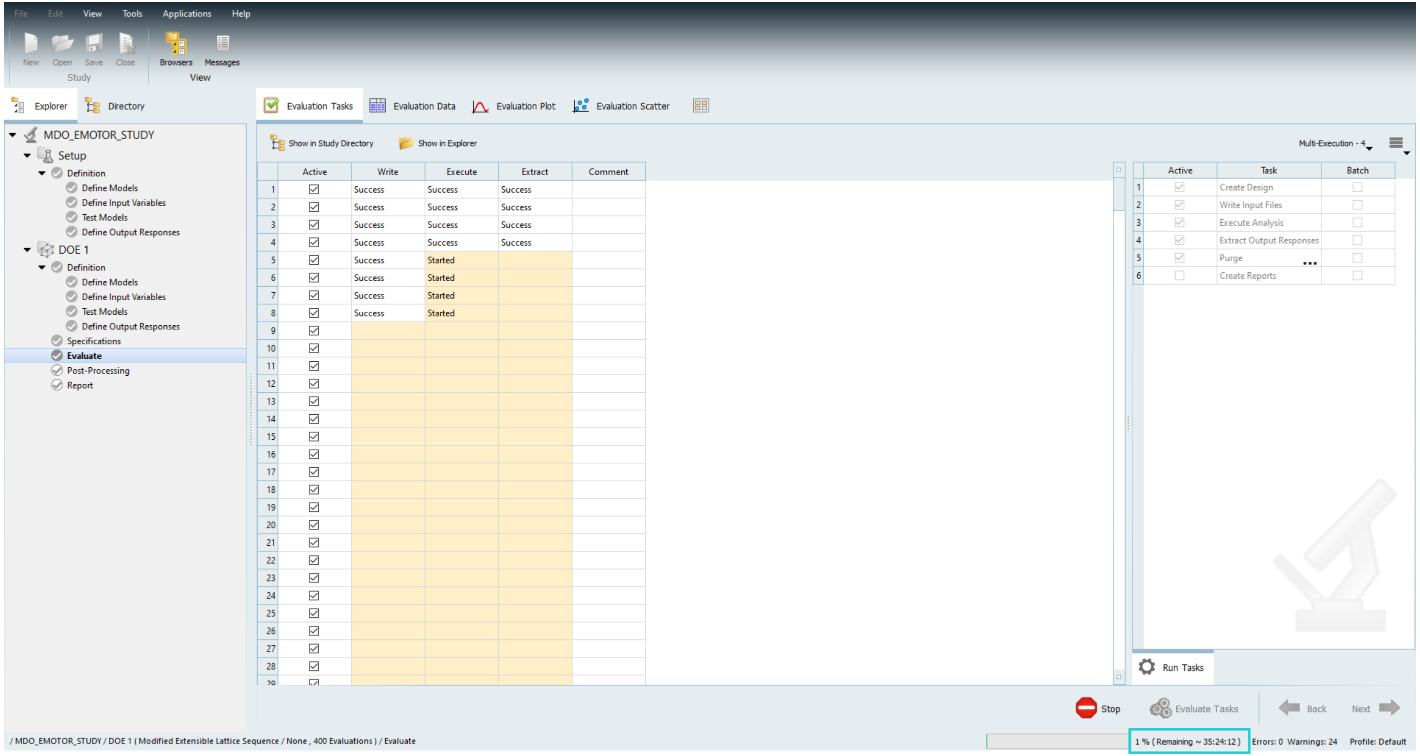
*Computation time is* ***25*** *hours*




***Attention: the multi-execution number depends on the computer system. Each execution need at least 15 G of RAM.***

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

Evaluate tasks in DOE analysis




*Estimated computation time*



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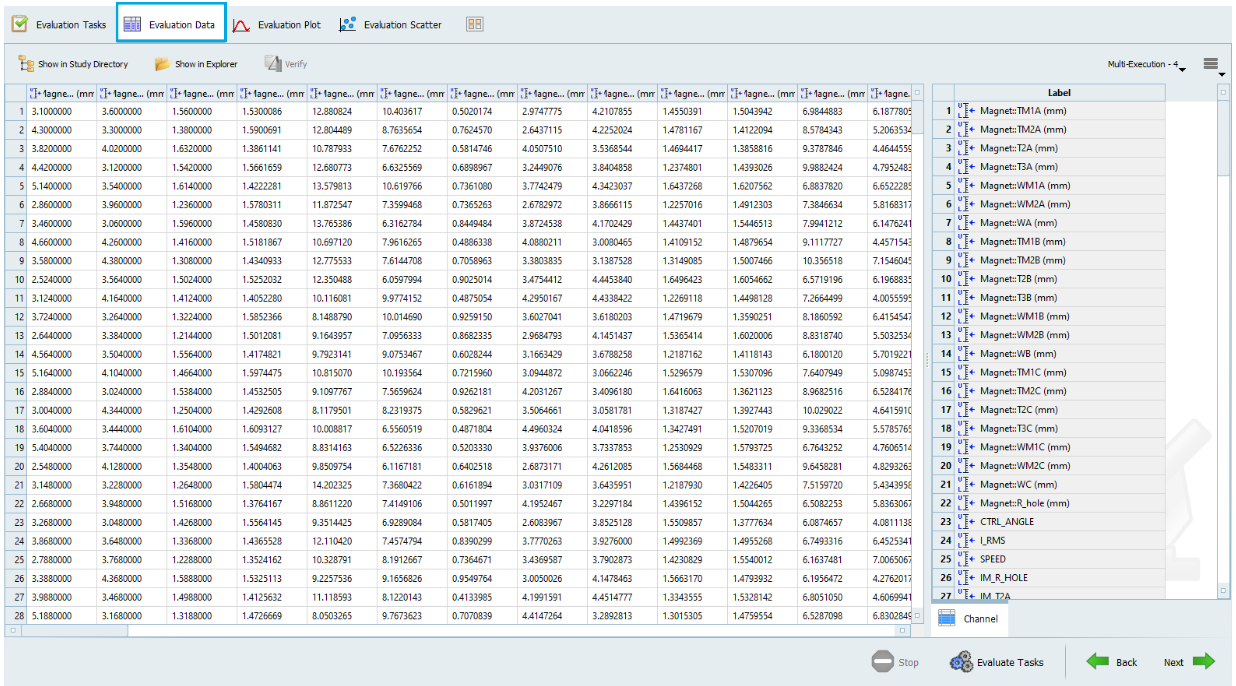
# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- View DOE analysis results

Click on [Evaluation Data] to see all the evaluated combinations of input values and the results




| | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... (mm | Magne... |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.1000000 | 3.6000000 | 1.5600000 | 1.5300086 | 12.880824 | 10.403617 | 0.5020174 | 2.9747775 | 4.2107855 | 1.4550391 | 1.5043942 | 6.9844883 | 6.1877805 |
| 2 | 4.3000000 | 3.3000000 | 1.3800000 | 1.5900691 | 12.804489 | 8.7635654 | 0.7624570 | 2.6437115 | 4.2252024 | 1.4781167 | 1.4122094 | 8.5784343 | 5.2063534 |
| 3 | 3.8200000 | 4.0200000 | 1.6320000 | 1.3861141 | 10.787933 | 7.6762252 | 0.5814746 | 4.0507510 | 3.5368544 | 1.4694417 | 1.3858816 | 9.3787846 | 4.4644559 |
| 4 | 4.4200000 | 3.1200000 | 1.5420000 | 1.5661659 | 12.680773 | 6.6325569 | 0.6898967 | 3.2449076 | 3.8404858 | 1.2374801 | 1.4393026 | 9.9882424 | 4.7952483 |
| 5 | 5.1400000 | 3.5400000 | 1.6140000 | 1.4222281 | 13.579813 | 10.619766 | 0.7361080 | 3.7742479 | 4.3423037 | 1.6437268 | 1.6207562 | 6.8837820 | 6.6522285 |
| 6 | 2.8600000 | 3.9600000 | 1.2360000 | 1.5780311 | 11.872547 | 7.3599468 | 0.7365263 | 2.6782972 | 3.8666115 | 1.2257016 | 1.4912303 | 7.3846634 | 5.8168317 |
| 7 | 3.4600000 | 3.0600000 | 1.5960000 | 1.4580830 | 13.765386 | 6.3162784 | 0.8449484 | 3.8724538 | 4.1702429 | 1.4437401 | 1.5446513 | 7.9941212 | 6.1476241 |
| 8 | 4.6600000 | 4.2600000 | 1.4160000 | 1.5181867 | 10.697120 | 7.9616265 | 0.4886338 | 4.0880211 | 3.0080465 | 1.4109152 | 1.4879654 | 9.1117727 | 4.4571543 |
| 9 | 3.5800000 | 4.3800000 | 1.3080000 | 1.4340933 | 12.775533 | 7.6144708 | 0.7058963 | 3.3803835 | 3.1387528 | 1.3149085 | 1.5007466 | 10.356518 | 7.1546045 |
| 10 | 2.5240000 | 3.5640000 | 1.5024000 | 1.5252032 | 12.350488 | 6.0597994 | 0.9025014 | 3.4754412 | 4.4453840 | 1.6496423 | 1.6054662 | 6.5719196 | 6.1968835 |
| 11 | 3.1240000 | 4.1640000 | 1.4124000 | 1.4052280 | 10.116081 | 9.9774152 | 0.4875054 | 4.2950167 | 4.4338422 | 1.2269118 | 1.4498128 | 7.2664499 | 4.0055595 |
| 12 | 3.7240000 | 3.2640000 | 1.3224000 | 1.5852366 | 8.1488790 | 10.014690 | 0.9259150 | 3.6027041 | 3.6180203 | 1.4719679 | 1.3590251 | 8.1860592 | 6.4154547 |
| 13 | 2.6440000 | 3.3840000 | 1.2144000 | 1.5012081 | 9.1643957 | 7.0956333 | 0.8682335 | 3.2684793 | 4.1451437 | 1.5365414 | 1.6020006 | 8.8318740 | 5.5032534 |
| 14 | 4.5640000 | 3.5040000 | 1.5564000 | 1.4174821 | 9.7923141 | 9.0753467 | 0.6028244 | 3.1663429 | 3.6788258 | 1.2187162 | 1.4118143 | 6.1800120 | 5.7019221 |
| 15 | 5.1640000 | 4.1040000 | 1.4664000 | 1.5974475 | 10.815070 | 10.193564 | 0.7215960 | 3.0944872 | 3.0662246 | 1.5296579 | 1.5307096 | 7.6407949 | 5.0987453 |
| 16 | 2.8840000 | 3.0240000 | 1.5384000 | 1.4532505 | 9.1097767 | 7.5659624 | 0.9262181 | 4.2031267 | 3.4096180 | 1.6416063 | 1.3621123 | 8.9682516 | 6.5284176 |
| 17 | 3.0040000 | 4.3440000 | 1.2504000 | 1.4292608 | 8.1179501 | 8.2319375 | 0.5829621 | 3.5064661 | 3.0581781 | 1.3187427 | 1.3927443 | 10.029022 | 4.6415910 |
| 18 | 3.6040000 | 3.4440000 | 1.6104000 | 1.6093127 | 10.008817 | 6.5560519 | 0.4871804 | 4.4960324 | 4.0418596 | 1.3427491 | 1.5207019 | 9.3368534 | 5.5785765 |
| 19 | 5.4040000 | 3.7440000 | 1.3404000 | 1.5494682 | 8.8314163 | 6.5226336 | 0.5203330 | 3.9376006 | 3.7337853 | 1.2530929 | 1.5793725 | 6.7643252 | 4.7606514 |
| 20 | 2.5480000 | 4.1280000 | 1.3548000 | 1.4004063 | 9.8509754 | 6.1167181 | 0.6402518 | 2.6873171 | 4.2612085 | 1.5684468 | 1.5483311 | 9.6458281 | 4.8293263 |
| 21 | 3.1480000 | 3.2280000 | 1.2648000 | 1.5804474 | 14.202325 | 7.3680422 | 0.6161894 | 3.0317109 | 3.6435951 | 1.2187930 | 1.4226405 | 7.5159720 | 5.4343958 |
| 22 | 2.6680000 | 3.9480000 | 1.5168000 | 1.3764167 | 8.8611220 | 7.4149106 | 0.5011997 | 4.1952467 | 3.2297184 | 1.4396152 | 1.5044265 | 6.5082253 | 5.8363067 |
| 23 | 3.2680000 | 3.0480000 | 1.4268000 | 1.5564145 | 9.3514425 | 6.9289084 | 0.5817405 | 2.6083967 | 3.8525128 | 1.5509857 | 1.3777634 | 6.0874657 | 4.0811138 |
| 24 | 3.8680000 | 3.6480000 | 1.3368000 | 1.4365528 | 12.110420 | 7.4574794 | 0.8390299 | 3.7770263 | 3.9276000 | 1.4992369 | 1.4955268 | 6.7493316 | 6.4525341 |
| 25 | 2.7880000 | 3.7680000 | 1.2288000 | 1.3524162 | 10.328791 | 8.1912667 | 0.7364671 | 3.4369587 | 3.7902873 | 1.4230829 | 1.5540012 | 6.1637481 | 7.0065067 |
| 26 | 3.3880000 | 4.3680000 | 1.5888000 | 1.5325113 | 9.2257536 | 9.1656826 | 0.9549764 | 3.0050026 | 4.1478463 | 1.5663170 | 1.4793932 | 6.1956472 | 4.2762017 |
| 27 | 3.9880000 | 3.4680000 | 1.4988000 | 1.4125632 | 11.118593 | 8.1220143 | 0.4133985 | 4.1991591 | 4.4514777 | 1.3343555 | 1.5328142 | 6.8051050 | 4.6069941 |
| 28 | 5.1880000 | 3.1680000 | 1.3188000 | 1.4726669 | 8.0503265 | 9.7673623 | 0.7070839 | 4.4147264 | 3.2892813 | 1.3015305 | 1.4759554 | 6.5287098 | 6.8302849 |

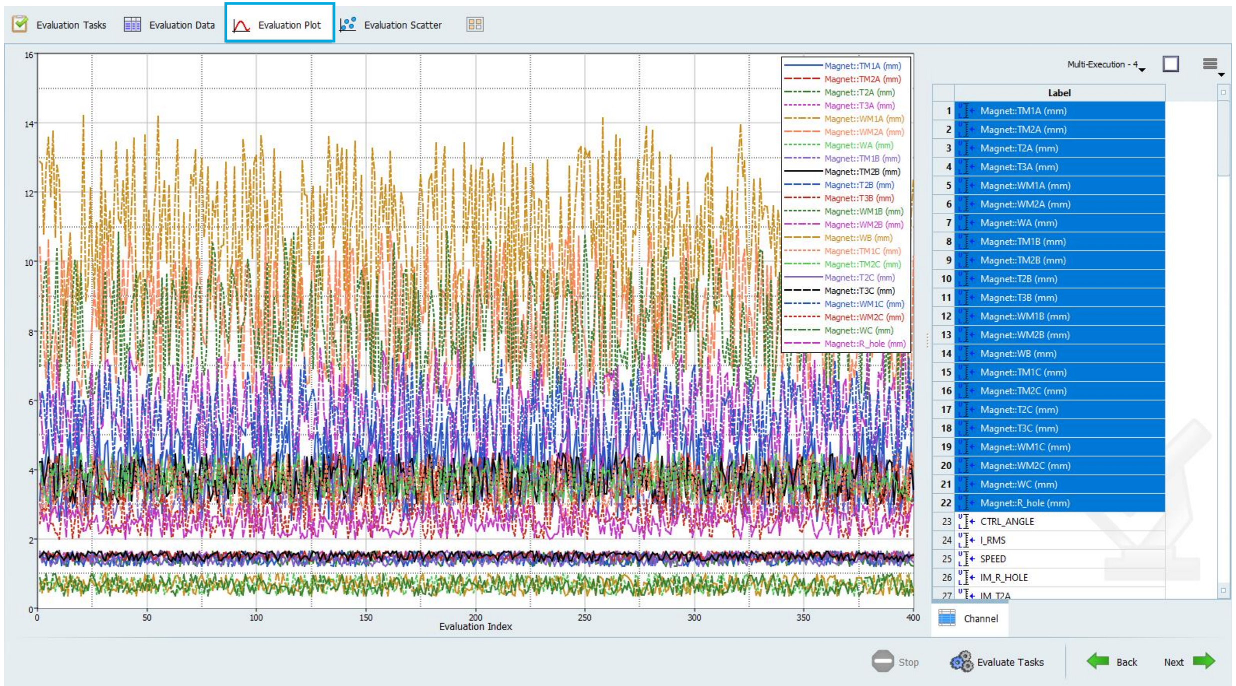
| | Label |
|---|---|
| 1 | Magnet::TM1A (mm) |
| 2 | Magnet::TM2A (mm) |
| 3 | Magnet::T2A (mm) |
| 4 | Magnet::T3A (mm) |
| 5 | Magnet::WM1A (mm) |
| 6 | Magnet::WM2A (mm) |
| 7 | Magnet::WA (mm) |
| 8 | Magnet::TM1B (mm) |
| 9 | Magnet::TM2B (mm) |
| 10 | Magnet::T2B (mm) |
| 11 | Magnet::T3B (mm) |
| 12 | Magnet::WM1B (mm) |
| 13 | Magnet::WM2B (mm) |
| 14 | Magnet::WB (mm) |
| 15 | Magnet::TM1C (mm) |
| 16 | Magnet::TM2C (mm) |
| 17 | Magnet::T2C (mm) |
| 18 | Magnet::T3C (mm) |
| 19 | Magnet::WM1C (mm) |
| 20 | Magnet::WM2C (mm) |
| 21 | Magnet::WC (mm) |
| 22 | Magnet::R_hole (mm) |
| 23 | CTRL_ANGLE |
| 24 | I_RMS |
| 25 | SPEED |
| 26 | IM_R_HOLE |
| 27 | IM_T2A |

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- View DOE analysis results

Click on [Evaluation Plot] to plot the curves of parameters during the evaluation task

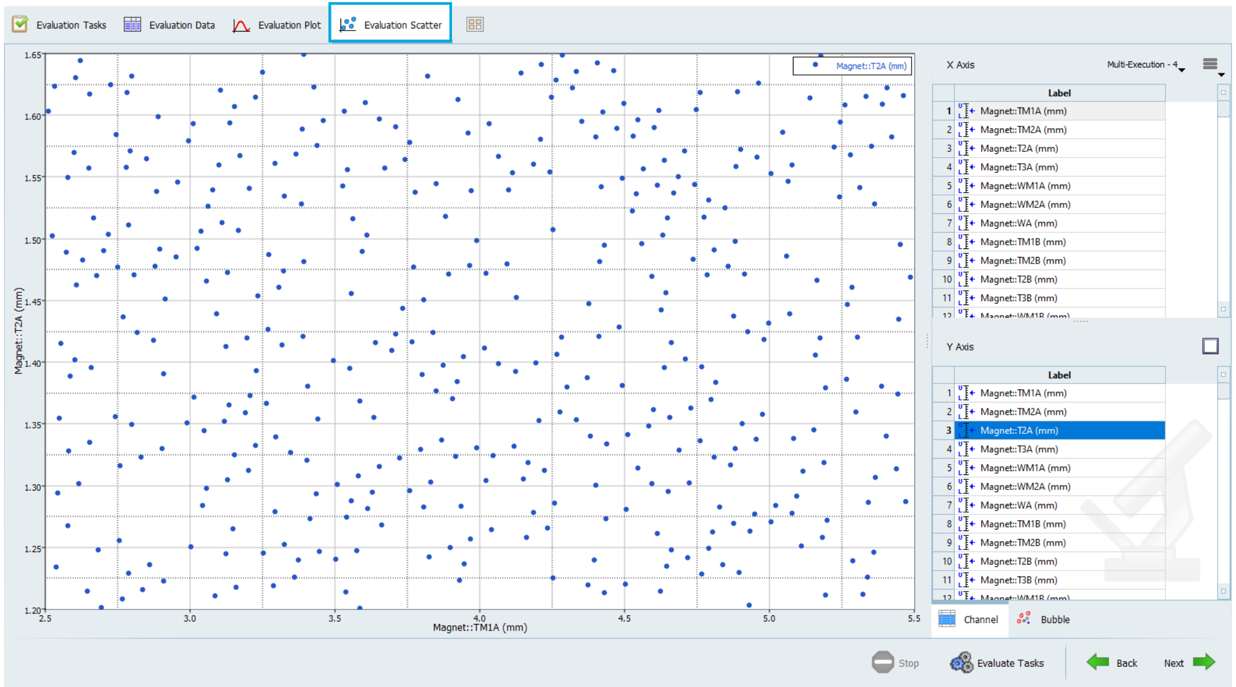


# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- View DOE analysis results

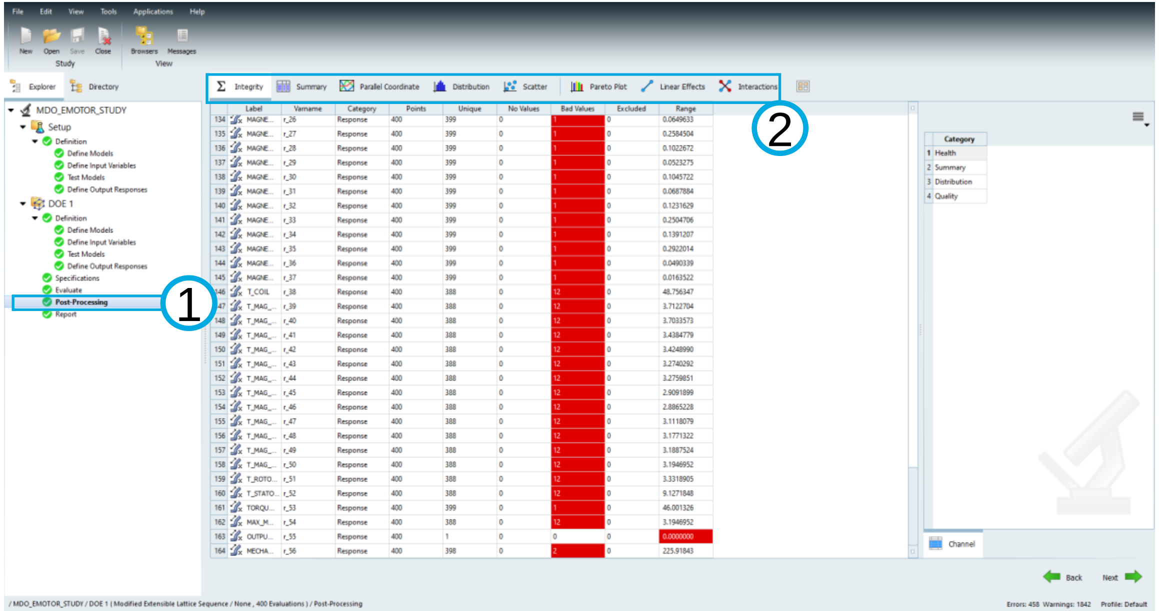
Click on [Evaluation Scatter] to plot the related curve between two evaluated parameters



# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis post-processing

| Step | Action |
|---|---|
| 1 | Click on [Post-Processing] in the [DOE 1] model |
| 2 | Use the HyperStudy function to analyze the DOE results |



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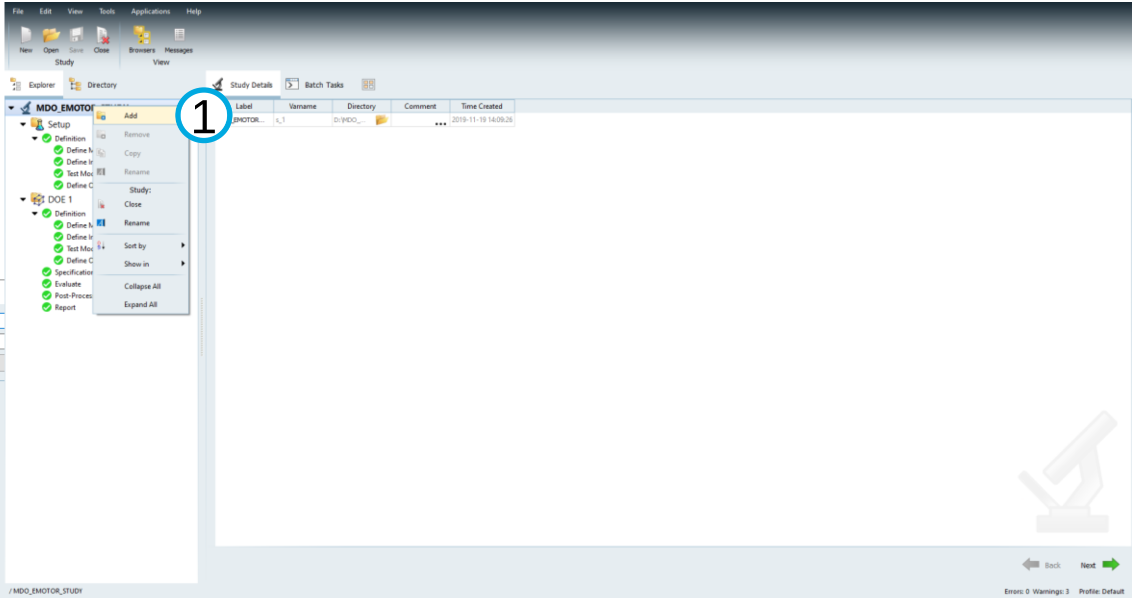
# FIT FUNCTION COMPUTATION

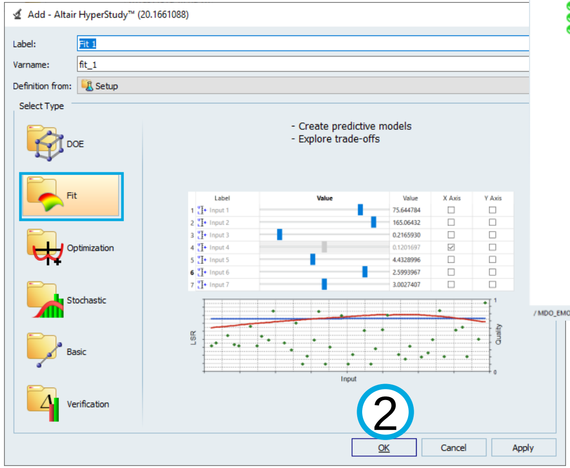
# FIT FUNCTION COMPUTATION

Initialization for fit function computation

- Add a new fit function analysis

| Step | Action |
|---|---|
| 1 | Right click on the project “MDO_MOTOR_STUDY”, click on [Add] |
| 2 | Select the type as “Fit”, click on [OK] |



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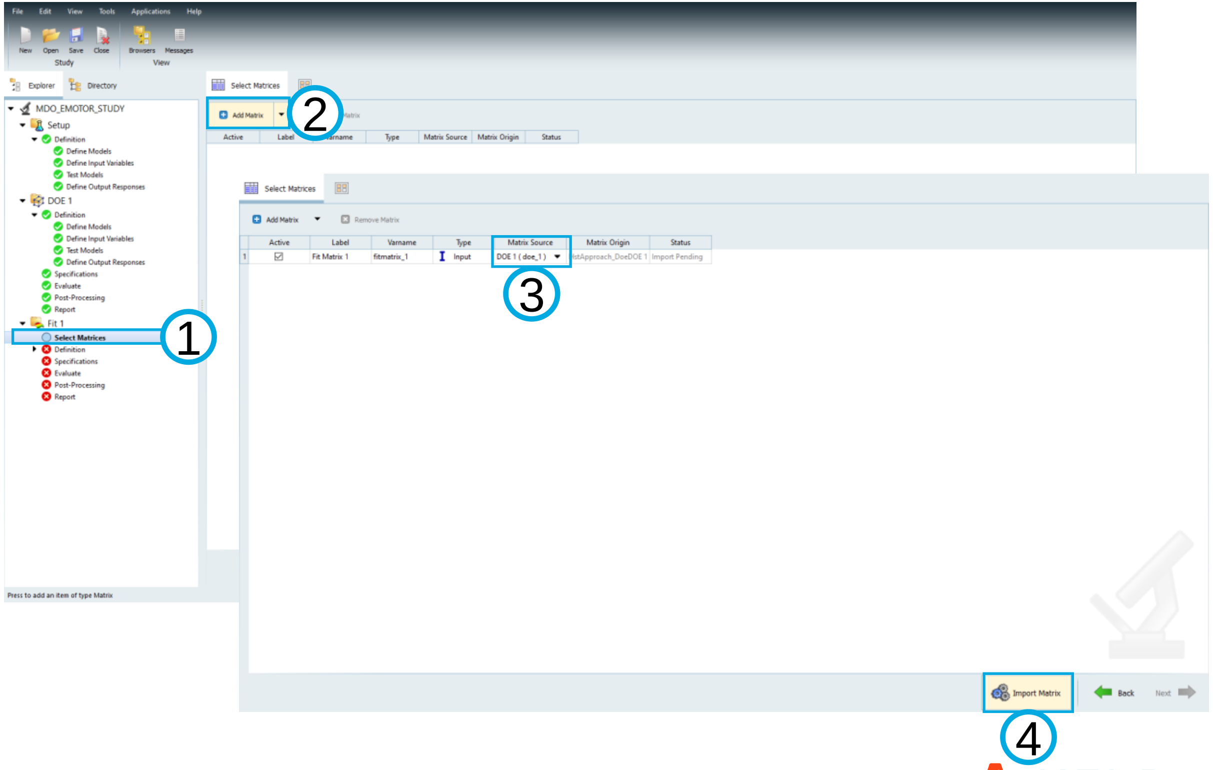
# FIT FUNCTION COMPUTATION

Initialization for fit function computation

- Define input matrix

| Step | Action |
|---|---|
| 1 | Click on [Fit 1] – [Select Matrices] |
| 2 | Click on [Add Matrix] |
| 3 | Select “DOE 1” as the Matrix Source |
| 4 | Click on [Import Matrix] |



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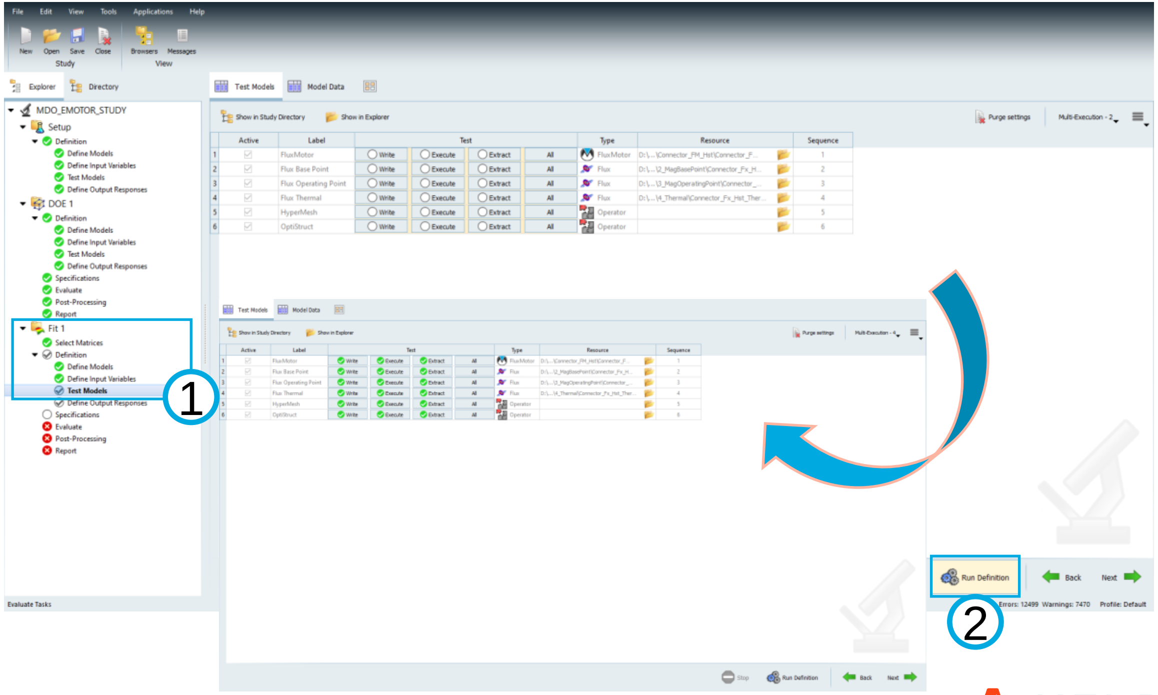
# FIT FUNCTION COMPUTATION

Initialization for fit function computation

- Verify model definitions

| Step | Action |
| --- | --- |
| 1 | Click on [Fit 1] – [Definition] – [Test Models] |
| 2 | Click on [Run Definition] to verify the models before computing fit functions |

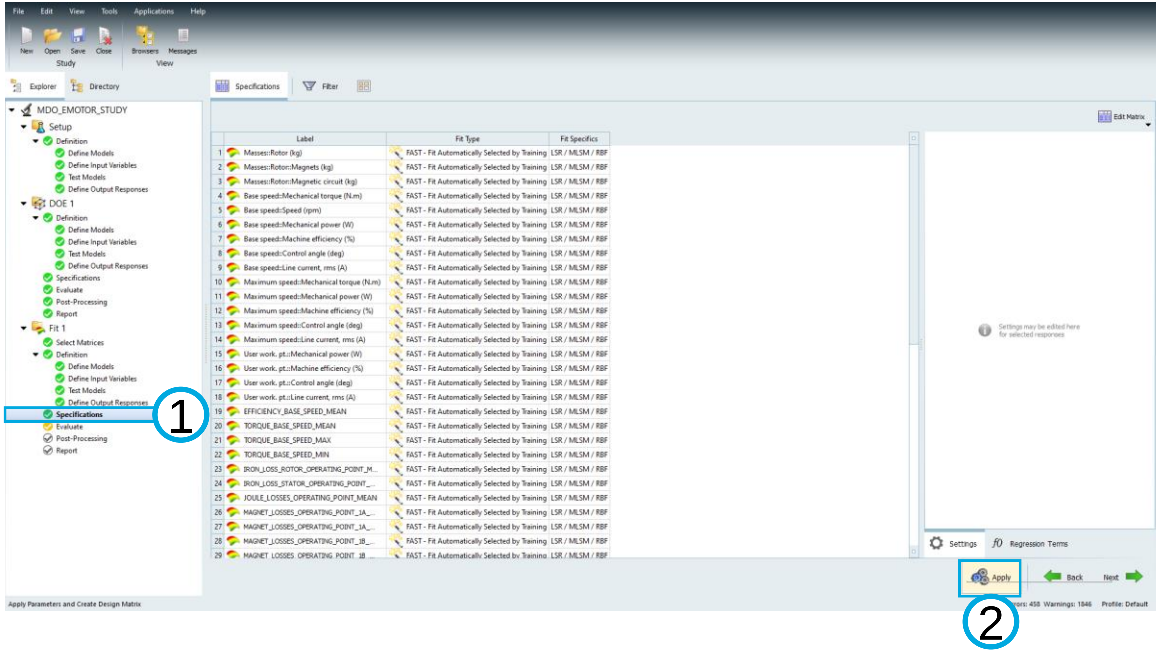


# FIT FUNCTION COMPUTATION

Initialization for fit function computation

- Define fit function setting

| Step | Action |
| --- | --- |
| 1 | Click on [Fit 1] - [Specifications] |
| 2 | Click on [Apply] to confirm the fit function setting |



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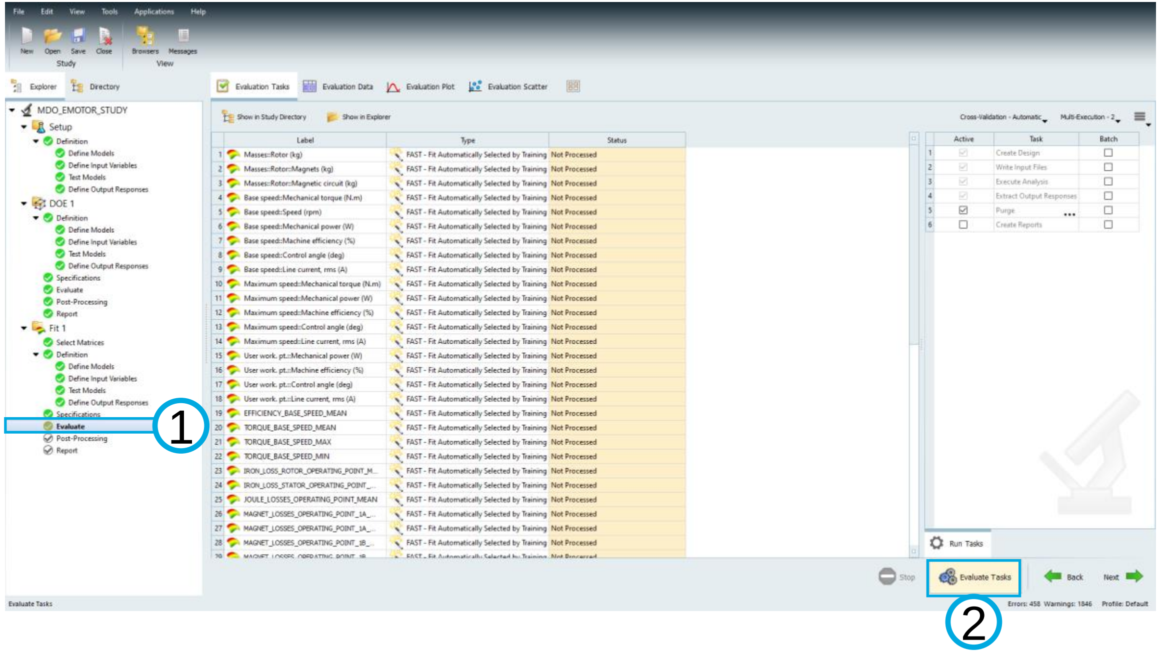
# FIT FUNCTION COMPUTATION

## Fit function computation process

- Evaluate tasks

| Step | Action |
|---|---|
| 1 | Click on [Evaluate] |
| 2 | Click on [Evaluate Tasks] to compute fit functions |

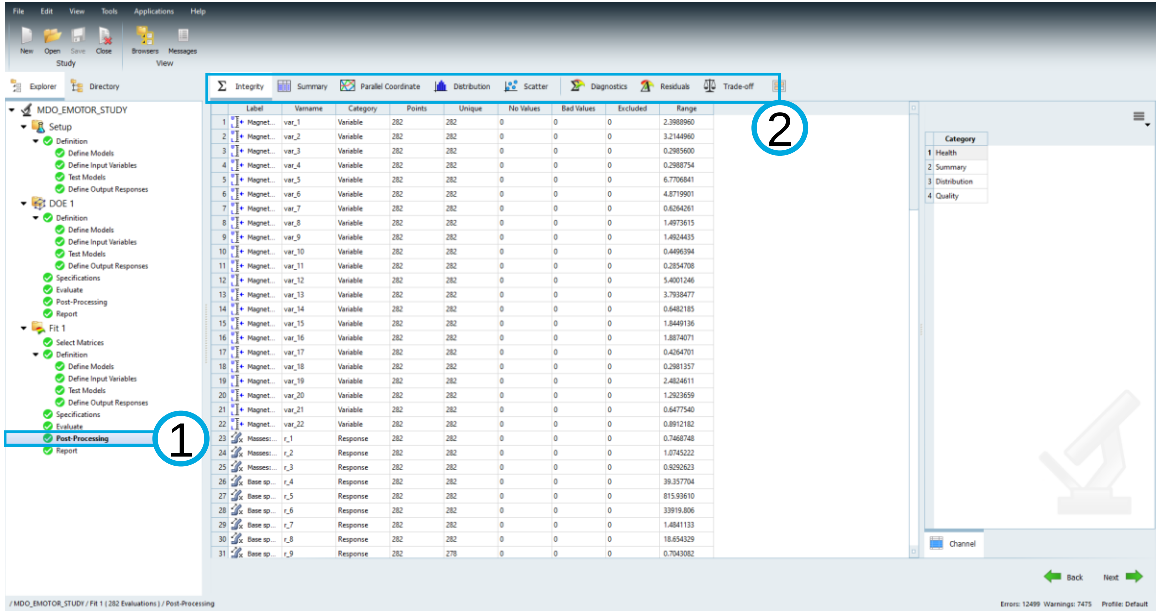


# FIT FUNCTION COMPUTATION

Fit function computation process

- Post-processing

| Step | Action |
|---|---|
| 1 | Click on [Fit 1] – [Post-Processing] |
| 2 | Use the HyperStudy function to analyze the fit function computation results |



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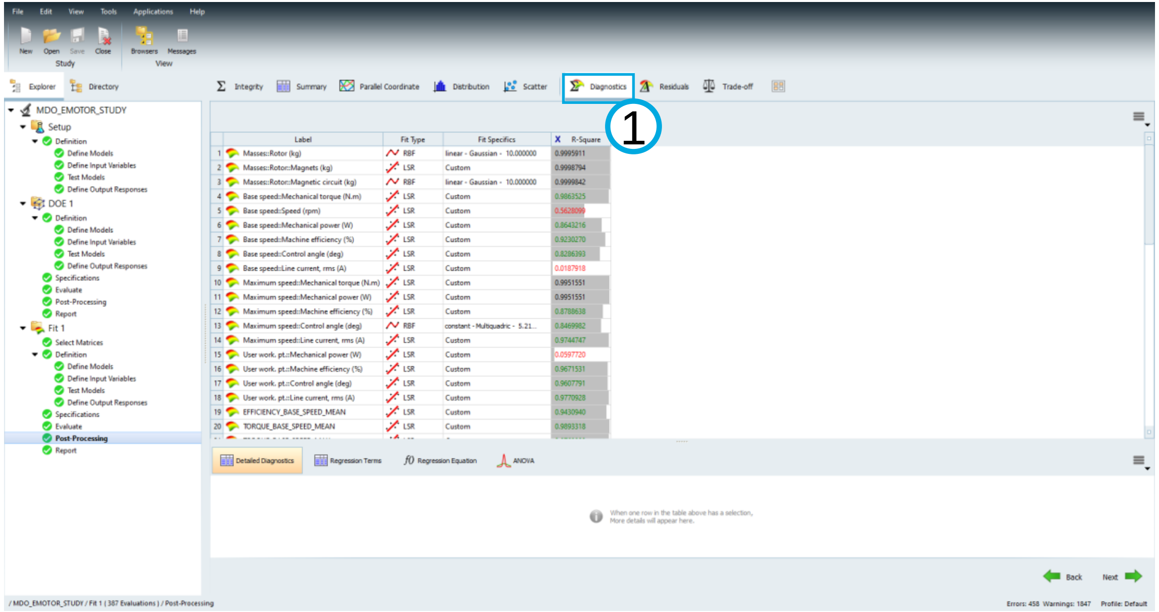
# FIT FUNCTION COMPUTATION

## Fit function computation process

- Post-processing

| Step | Action |
|---|---|
| 1 | Use the [Diagnostic] function to analyze the fit function computation quality |




***Note: if the value is closer to 1, the more accurate is the Fit function obtained.***



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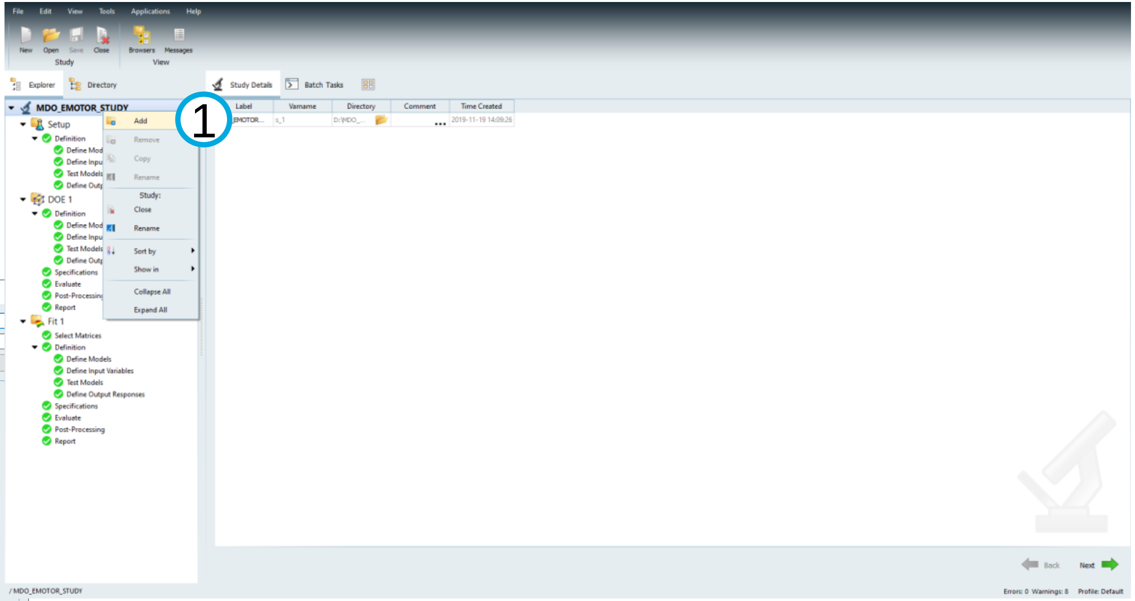
# OPTIMIZATION PROCESS

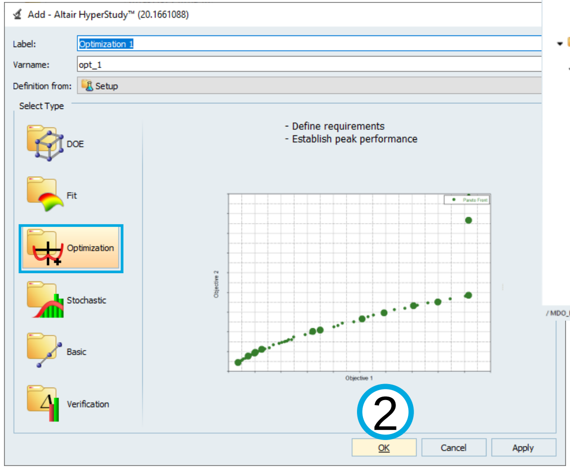
# OPTIMIZATION PROCESS

## Optimization initialization

- Add a new optimization application

| Step | Action |
|---|---|
| 1 | Right click on the project “MDO_MOTOR_STUDY”, click on [Add] |
| 2 | Select the type as “Optimization”, click on [OK] |



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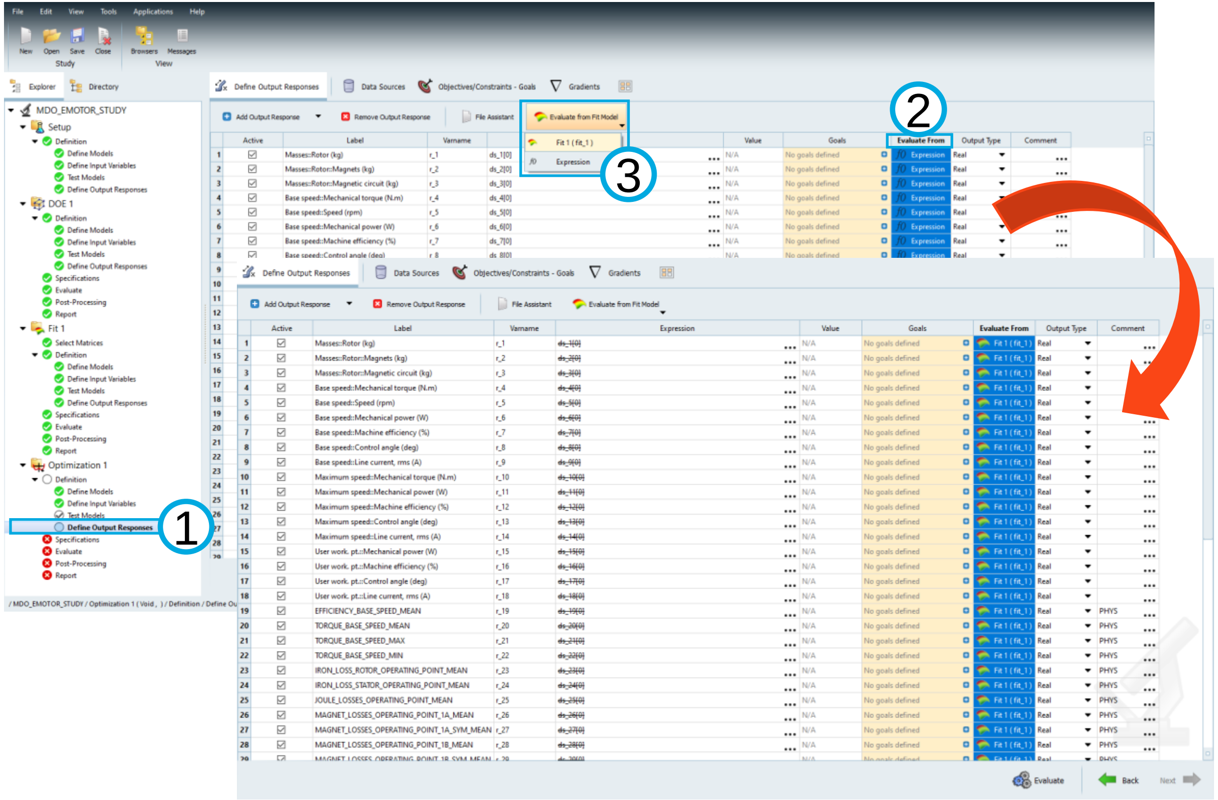
# OPTIMIZATION PROCESS

## Optimization initialization

- Link to fit function results

| Step | Action |
|---|---|
| 1 | Click on [Optimization 1] – [Definition] – [Define output Responses] |
| 2 | Click on [Evaluate From] to select all the output responses |
| 3 | Click on [Evaluate from Fit Model] – [Fit 1] to link the optimization with the fit functions |



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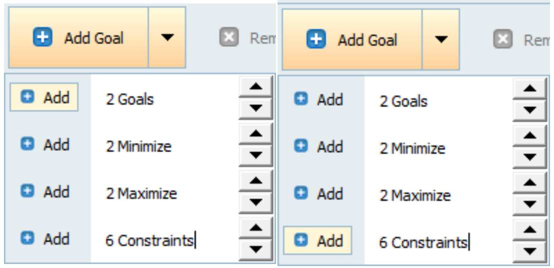
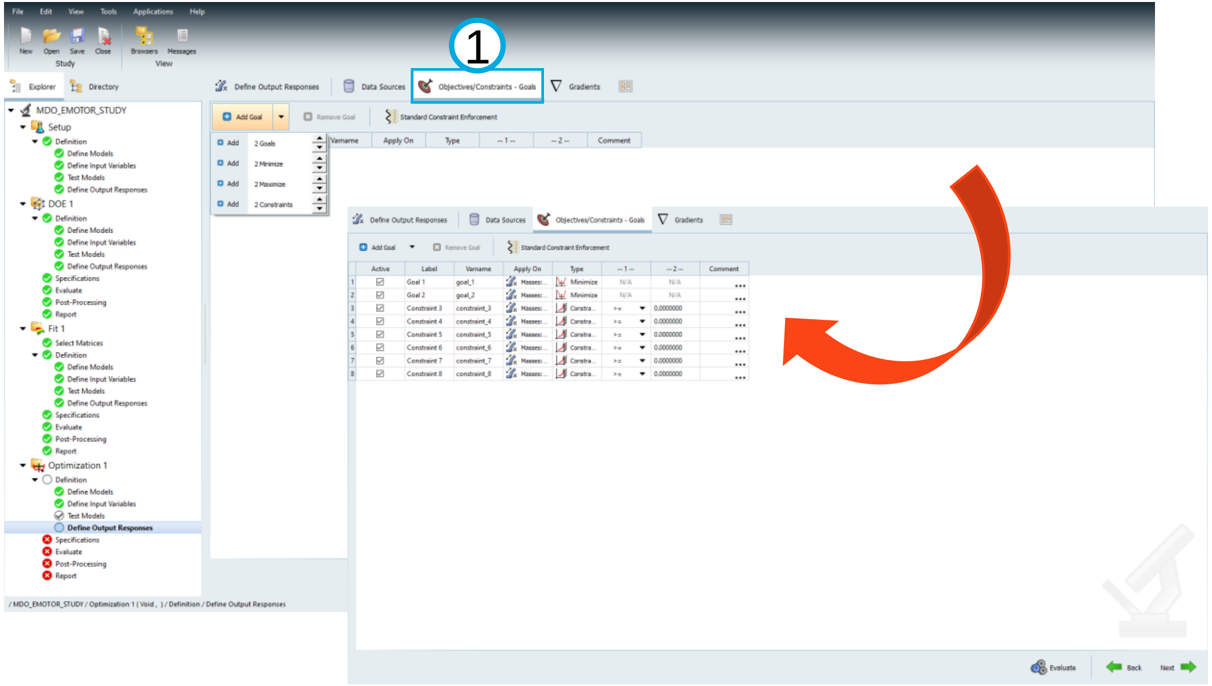
# OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

| Step | Action |
| --- | --- |
| 1 | Click on [Objectives/Constraints - goals] |
| 2 | Click on the icon Add Goal to add<br>- 3 Goals<br>- 6 constraints |



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# OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

| Step | Action |
|---|---|
| 1 | Modify the goals and constraints as shown in the following table |

| Label | Varname | Apply on | Type | 1 | 2 |
|---|---|---|---|---|---|
| MaxPowerBaseSpeed | goal_1 | Base speed::Mechanical power (W) ( r_6 ) | Maximize | | |
| MinRotorMass | goal_2 | Masses::Rotor (kg) ( r_1 ) | Minimize | | |
| TorqueBassSpeed | constraint_3 | Base speed::Mechanical torque (N.m) ( r_4 ) | Constraint | >= | 180 |
| PowerBassSpeed | constraint_4 | Base speed::Mechanical power (W) ( r_6 ) | Constraint | >= | 140000 |
| TemperatureWinding | constraint_5 | T_COIL ( r_38 ) | Constraint | <= | 180 |
| TorqueBassSpeedRipple | constraint_6 | TORQUE_BASE_SPEED_RIPPLE ( r_53 ) | Constraint | <= | 29 |
| TempMagnetMax | constraint_7 | MAX_MAGNET_TEMPERATURE ( r_54 ) | Constraint | <= | 100 |
| MechanicalStress | constraint_8 | MECHANICAL_STRESS_MAX ( r_56 ) | Constraint | <= | 400 |



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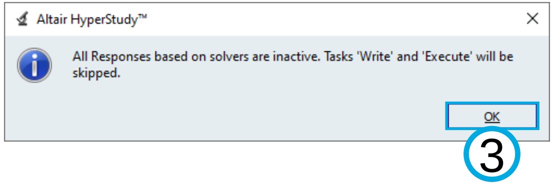
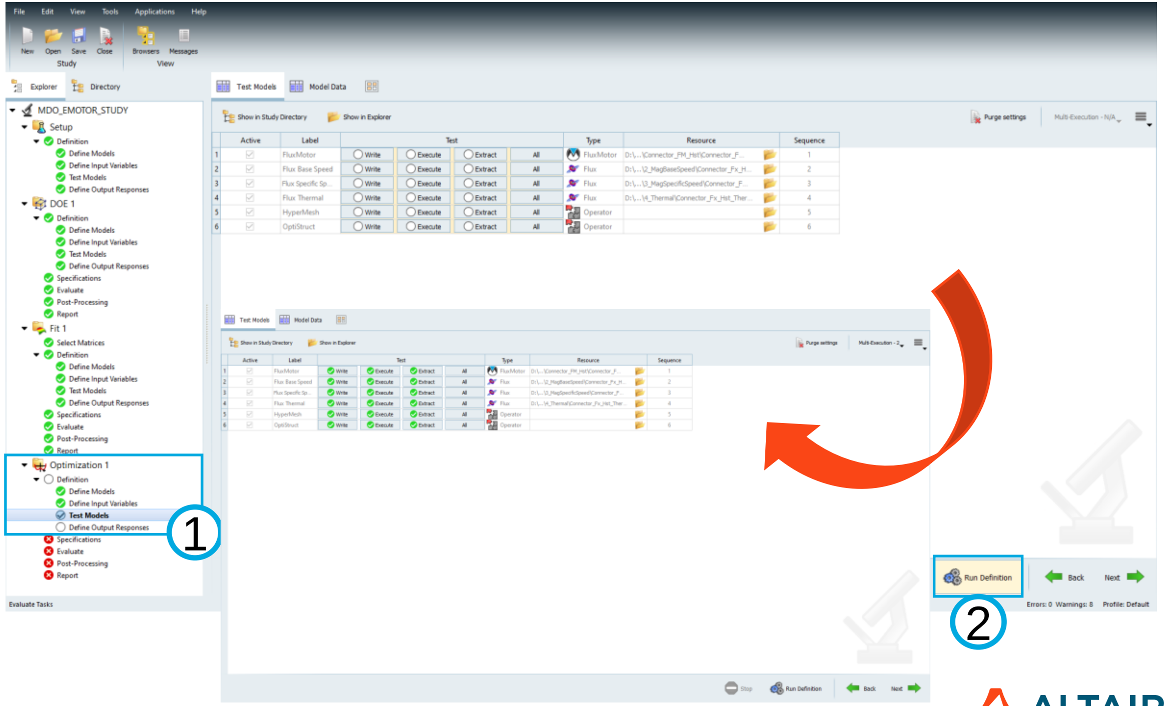
# OPTIMIZATION PROCESS

Optimization initialization

- Verify model definition

| Step | Action |
|---|---|
| 1 | Click on [Optimization 1] – [Definition] – [Test Models] |
| 2 | Click on [Run Definition] to verify the models before running optimization process |
| 3 | Click on [OK] |



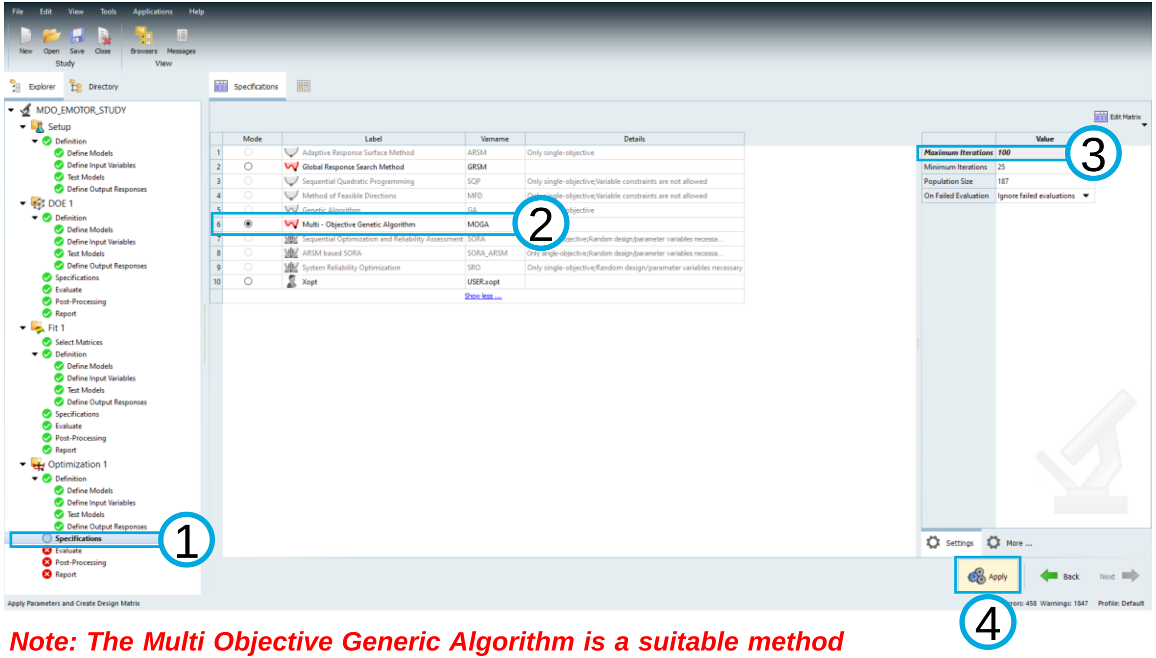



# OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting

| Step | Action |
|---|---|
| 1 | Click on [Specifications] |
| 2 | Select “MOGA” algorithm |
| 3 | Define the “Maximum Iteration” number |
| 4 | Click on [Apply] |



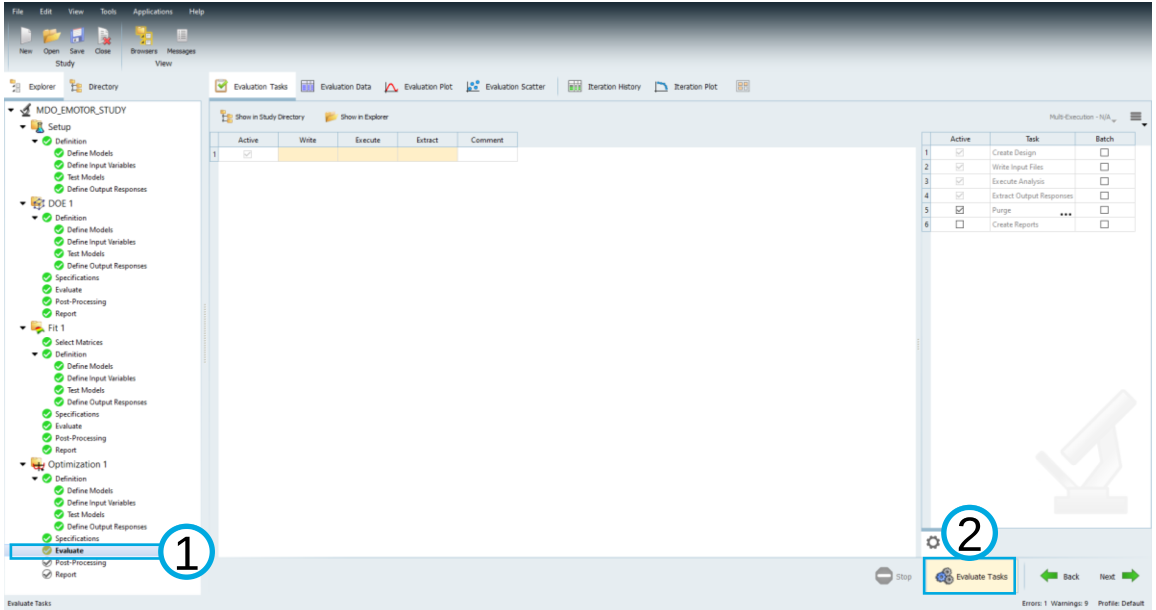

*Note: The Multi Objective Generic Algorithm is a suitable method for the optimization problem based on fit functions.*

# OPTIMIZATION PROCESS

## Optimization evaluation

- Evaluate tasks for the optimization problem

| Step | Action |
|---|---|
| 1 | Click on [Evaluate] |
| 2 | Click on [Evaluate Tasks] |




***Note: The optimization problem based on fit functions will cost just 15 minutes.***



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# OPTIMIZATION PROCESS

## Optimization evaluation

- Verify iteration convergence during the optimization process

| Step | Action |
|---|---|
| 1 | Click on [Iteration Plot] |



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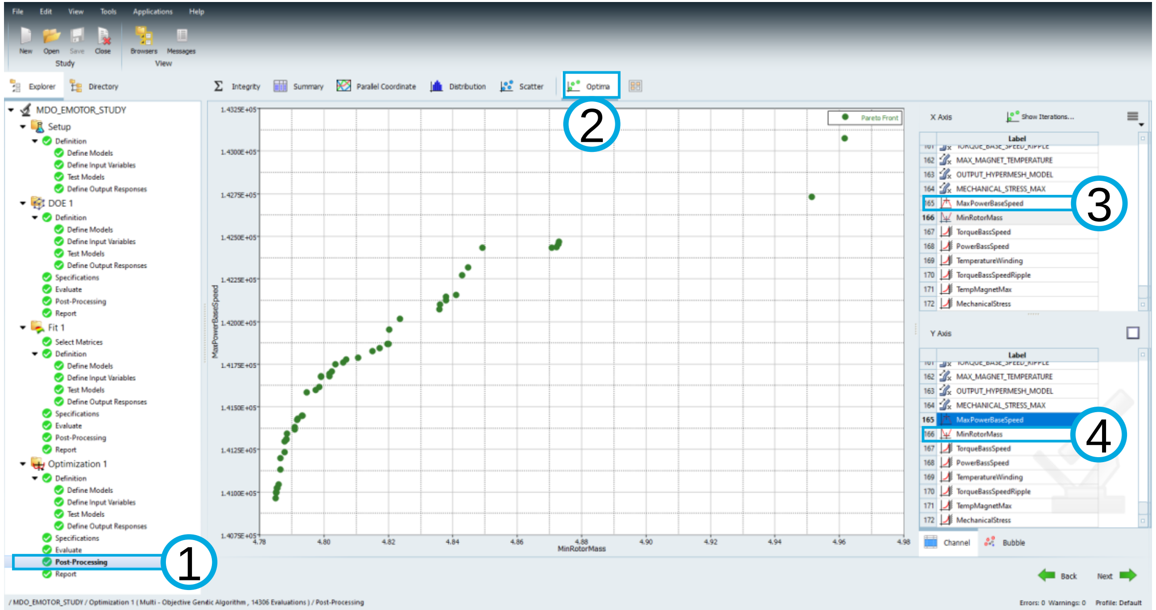
# OPTIMIZATION PROCESS

## Optimization post-processing

- Plot optimal curve

| Step | Action |
|---|---|
| 1 | Click on [Post-Processing] |
| 2 | Click on [Optimal] to see all the optimization results for the electric motor |
| 3 | Select the Goal “MinRotorMass” |
| 4 | Select the Goal “MaxPowerBaseSpeed” |



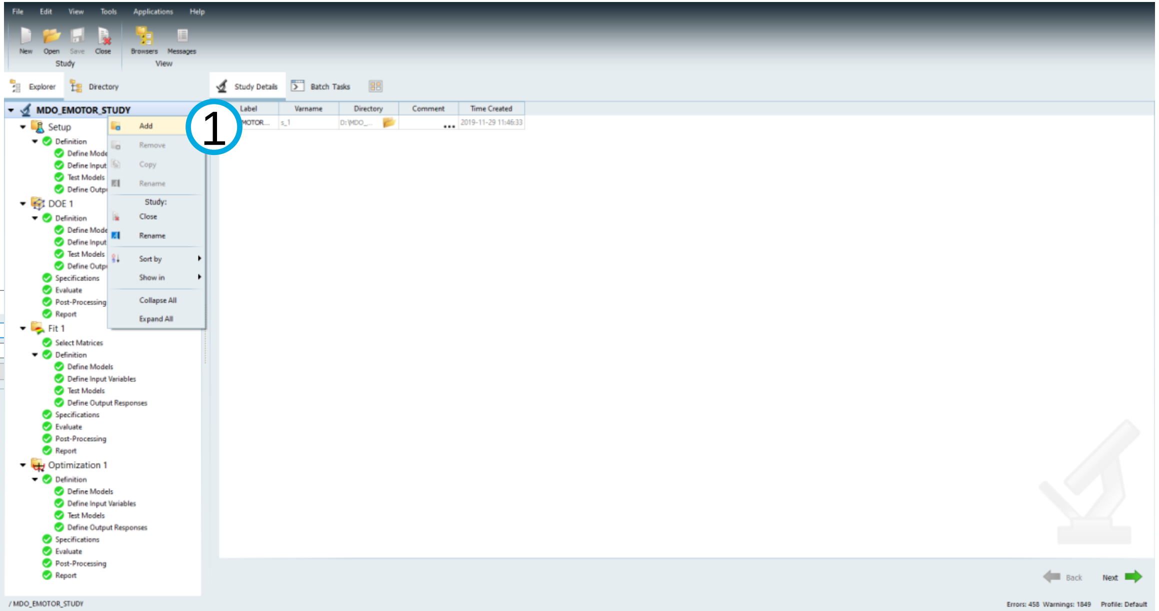
# OPTIMIZATION VERIFICATION

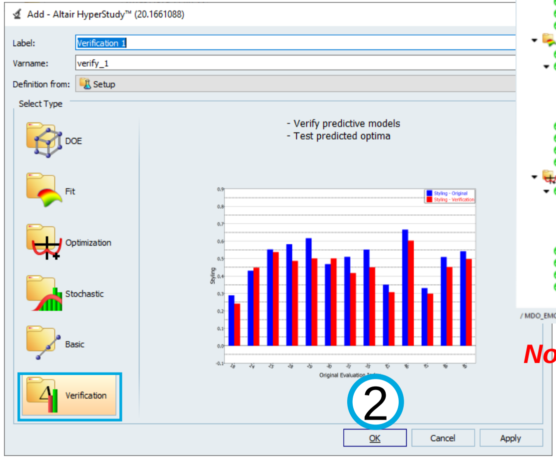
# OPTIMIZATION VERIFICATION

## Verification initialization

- Add a new verification

| Step | Action |
|---|---|
| 1 | Right click on the project “MDO_MOTOR_STUDY”, click on [Add] |
| 2 | Select the type as “Verification”, click on [OK] |




***Note: The results of optimization problem based on fit functions will need to be check with real model.***



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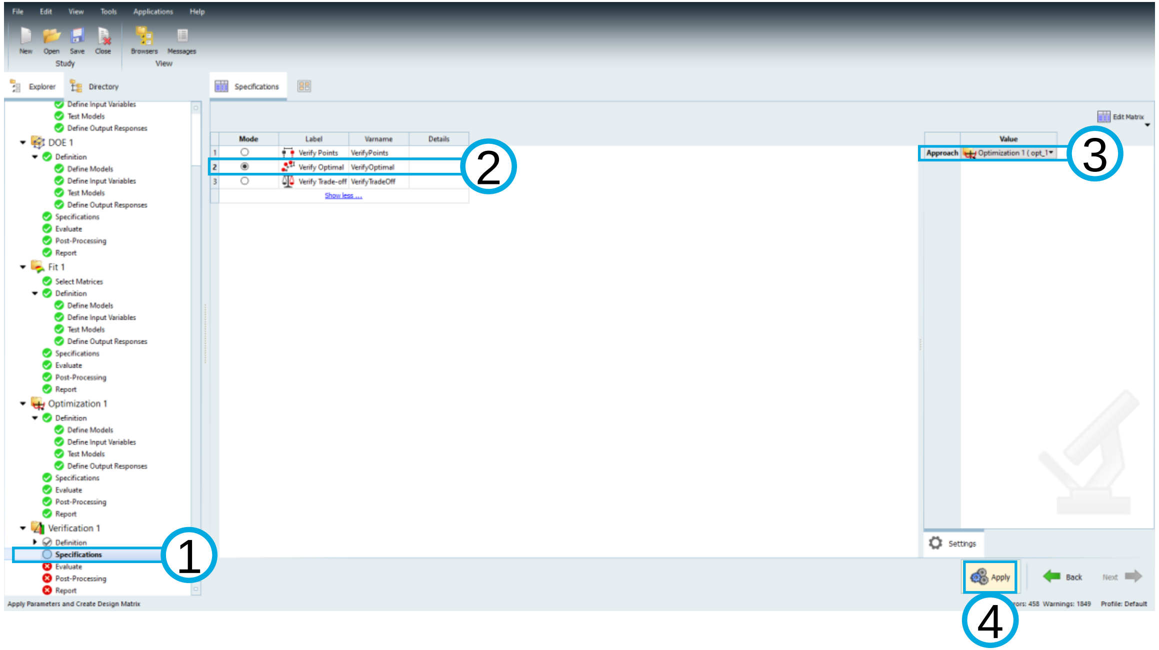
# OPTIMIZATION VERIFICATION

## Verification specification

- Define verification mode and original value

| Step | Action |
|---|---|
| 1 | Click on [Verification 1] – [Specification] |
| 2 | Select the verification mode as “Verify Optimal” |
| 3 | Verify if the value is from the “Optimization 1” |
| 4 | Click on [Apply] |



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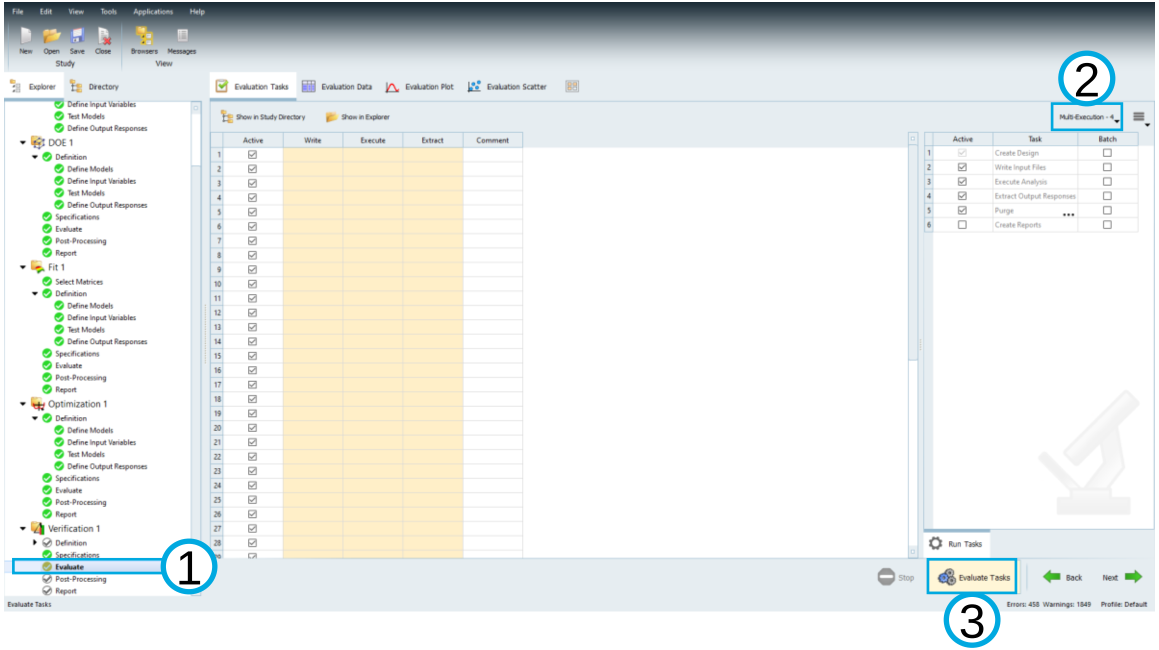
# OPTIMIZATION VERIFICATION

## Verification evaluation

- Evaluate the verification tasks

| Step | Action |
|---|---|
| 1 | Click on [Verification 1] – [Evaluate] |
| 2 | Click on [Multi-Execution] to define the multi-execution number |
| 3 | Click on [Evaluate Tasks] |



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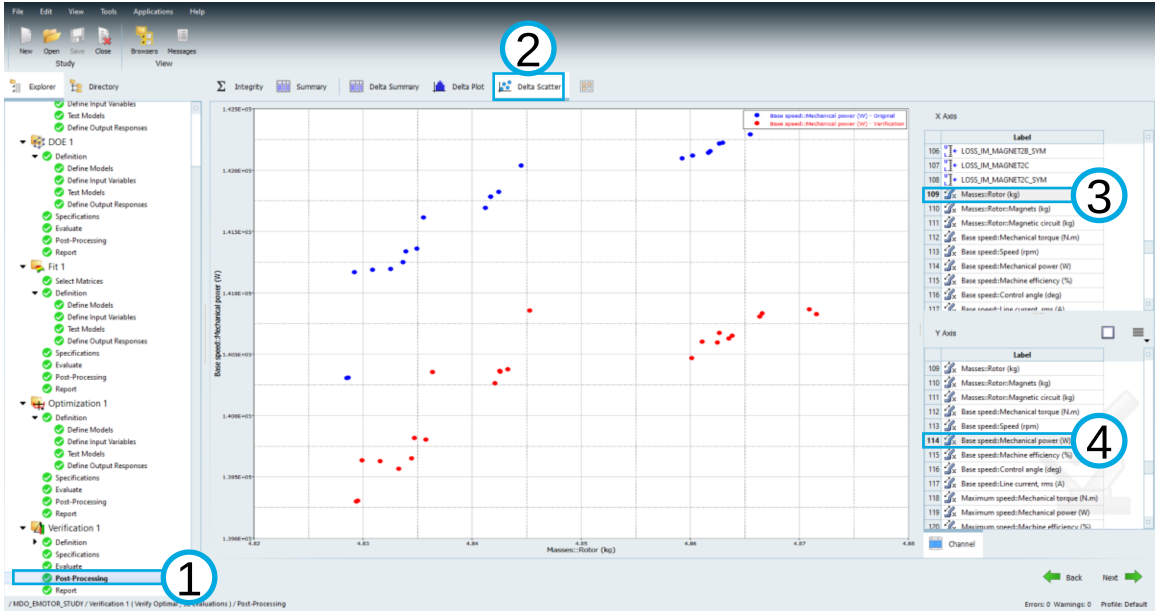
# OPTIMIZATION VERIFICATION

## Verification post-processing

- Plot the optimization curve with verification values

| Step | Action |
|---|---|
| 1 | Click on [Verification 1] – [Post-Processing] |
| 2 | Click on [Delta Scatter] |
| 3 | Select the variable 109 “Masses: Rotor” |
| 4 | Select the variable 114 “Base speed: Mechanical power” |




***Note: The difference between original results from the optimization base on fit function and the verification results is about 0.7%.***



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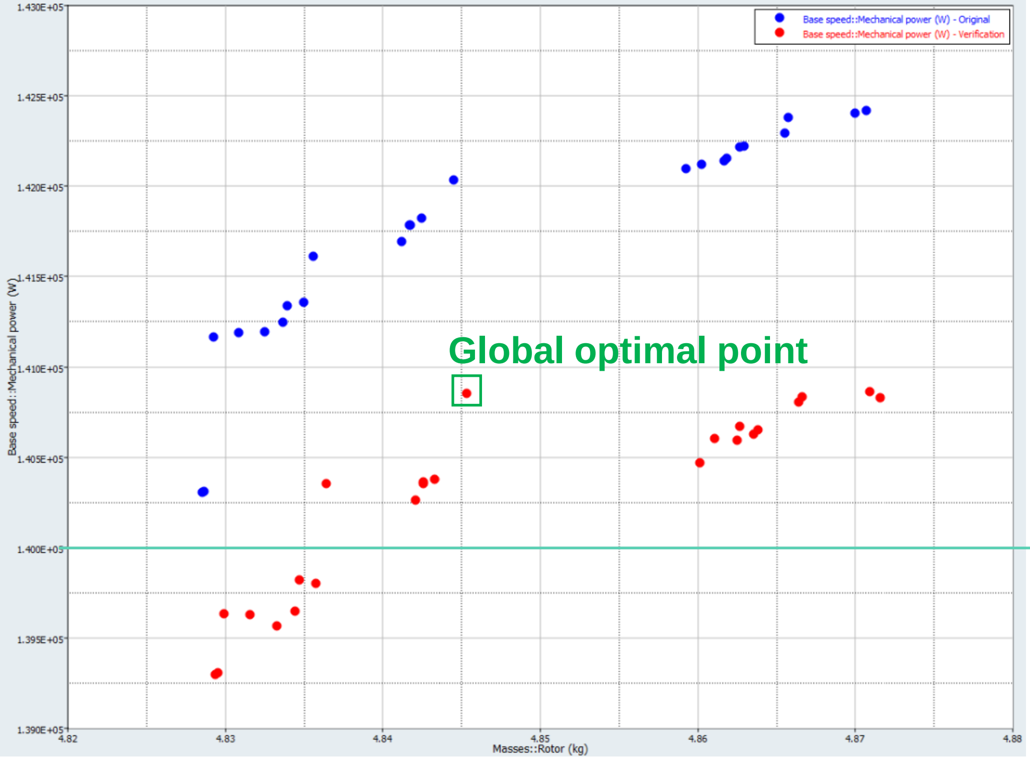
# OPTIMIZATION VERIFICATION

Verified optimization results

- Global optimal results




Objective power



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# OPTIMIZATION VERIFICATION

Verified optimization results

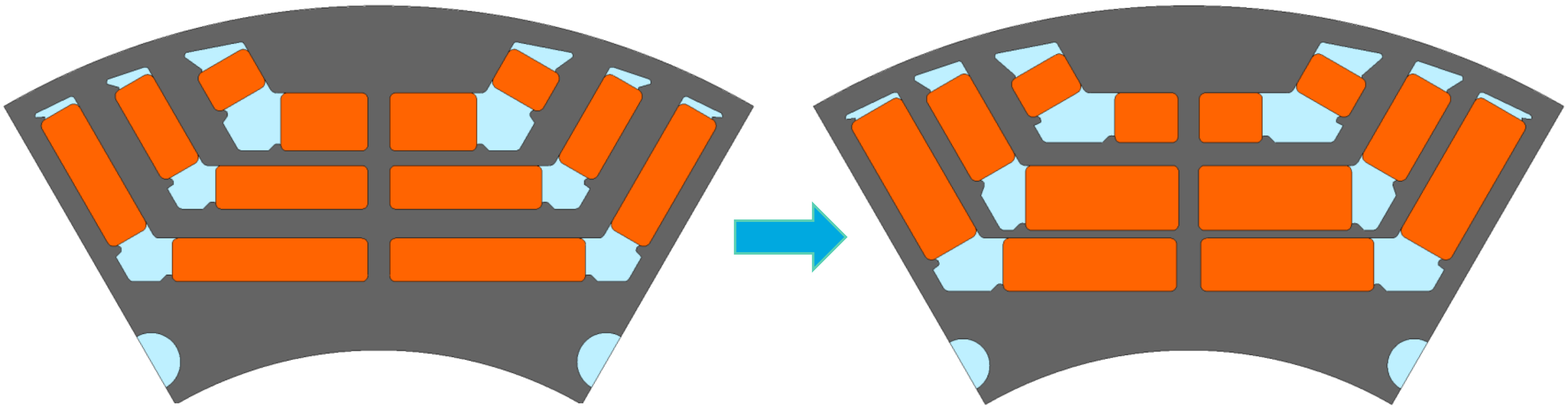
- Global optimal results comparison

| | Original value | Verified value | Difference (between verified value and original value) |
|---|---|---|---|
| Mechanical power at base point / W | 137818 | 140854.7 | 2.20% |
| Rotor mass / kg | 4.96 | 4.85 | -2.31% |
| Mechanical torque at base point / N*m | 184.21 | 181.43 | -1.51% |
| Mechanical torque ripple at base point / N*m | 43.11 | 34.78 | -19.33% |
| Winding temperature / °C | 151.01 | 159.37 | 5.54% |
| Magnet temperature / °C | 46.75 | 46.11 | -1.36% |
| Mechanical stress / MPa | 450.79 | 390.80 | -13.31% |

# OPTIMIZATION VERIFICATION

Verified optimization results

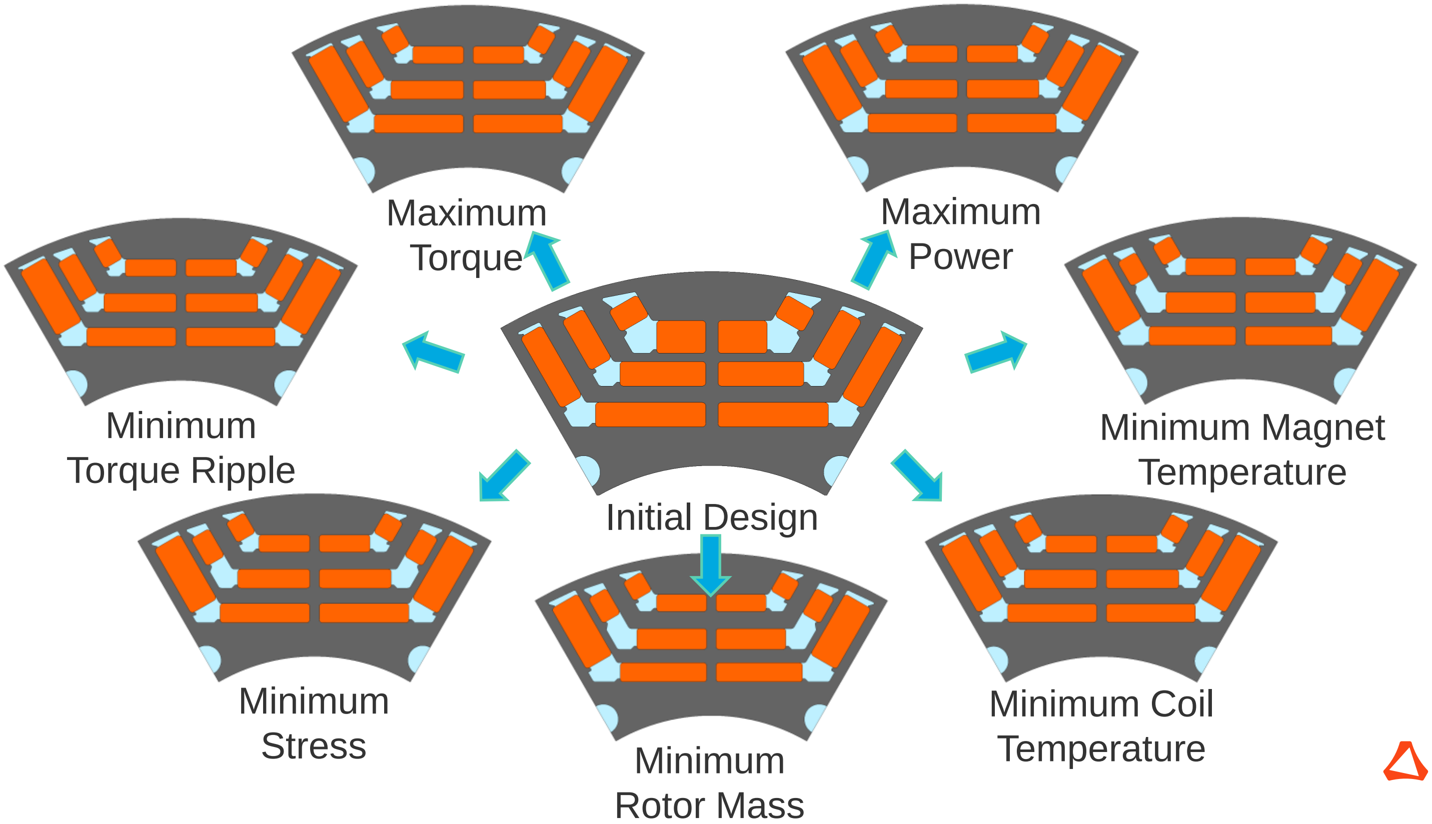
- Global optimal results



Initial Design　　　Optimal Design

# OPTIMIZATION VERIFICATION

Verified optimization: local optimization results for each goal and constraints



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# OPTIMIZATION VERIFICATION

Verified optimization: local optimization results for each goal and constraints

- Local optimal results

| | Original value | Local optimal point 1 | Local optimal point 2 | Local optimal point 3 | Local optimal point 4 |
|---|---|---|---|---|---|
| Mechanical power at base point / W | *137817.95* | 139299.49 | 139818.81 | 140356.21 | 140378.62 |
| Rotor mass / kg | *4.96* | **4.83** | 4.83 | 4.84 | 4.84 |
| Mechanical torque at base point / N*m | *184.21* | **182.36** | 181.77 | 181.56 | 181.57 |
| Mechanical torque ripple at base point / N*m | *43.11* | 34.59 | 34.99 | **34.19** | 34.26 |
| Winding temperature / °C | *151.01* | **158.04** | 159.07 | 159.23 | 159.22 |
| Magnet temperature / °C | *46.75* | 46.20 | 46.13 | 46.10 | **46.09** |
| Mechanical stress / MPa | *450.79* | 394.00 | **373.40** | 389.73 | 378.40 |



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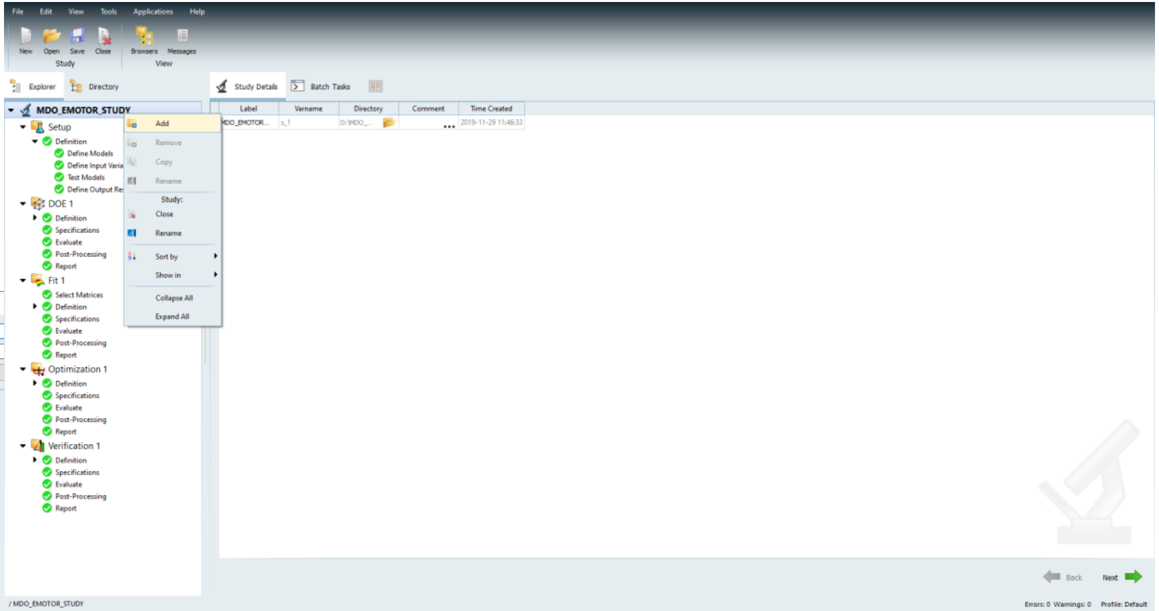
# STOCHASTIC STUDY AND RELIABILITY TEST

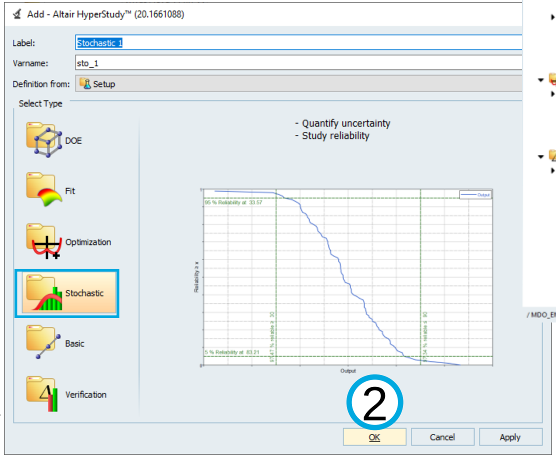
# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Add a new stochastic test

| Step | Action |
|---|---|
| 1 | Right click on the project “MDO_MOTOR_STUDY”, click on [Add] |
| 2 | Select the type as “Stochastic”, click on [OK] |



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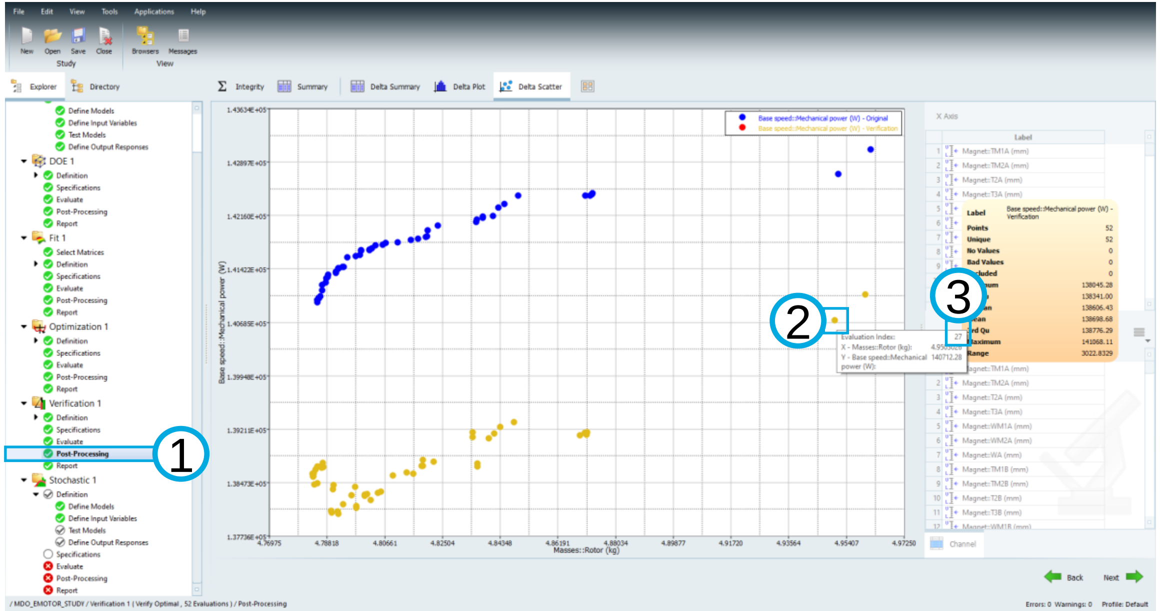
# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Select the “optimal” point

| Step | Action |
|---|---|
| 1 | Click on [Verification 1] – [Post-processing] |
| 2 | Select an optimal point in the optimization curve |
| 3 | In this case, the index of the optimal point is 27 |

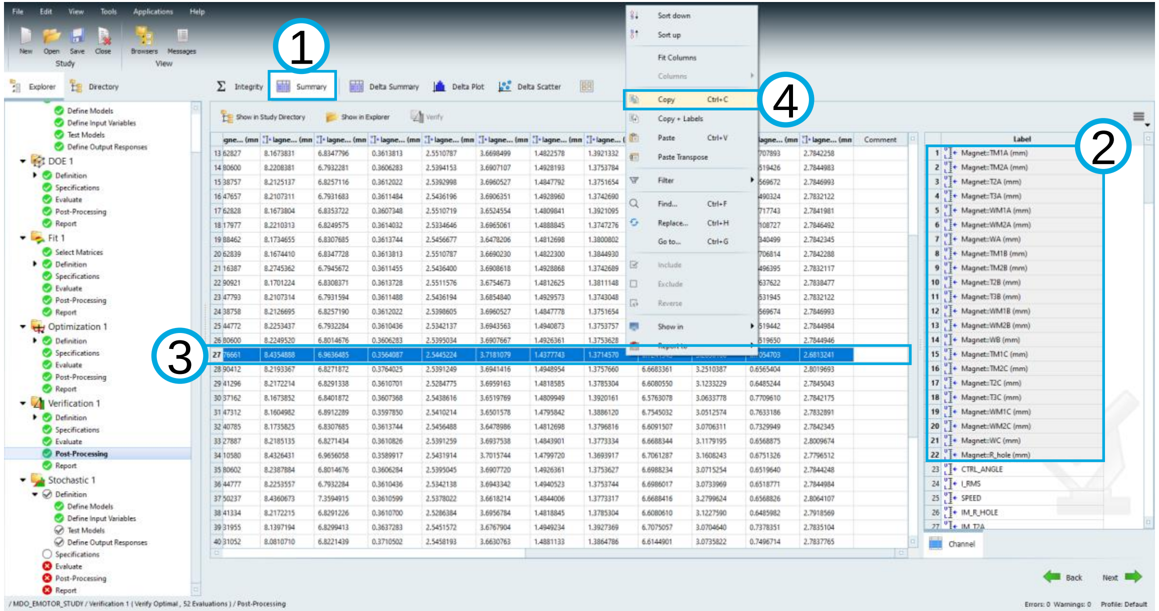


# STOCHASTIC STUDY AND RELIABILITY TEST

Stochastic study initialization

- Copy the geometric values of the “optimal” point

| Step | Action |
|---|---|
| 1 | Click on [Summary] |
| 2 | Select all the 22 geometric parameters |
| 3 | Select all the values in the row 27 |
| 4 | Right click and click on [Copy] |



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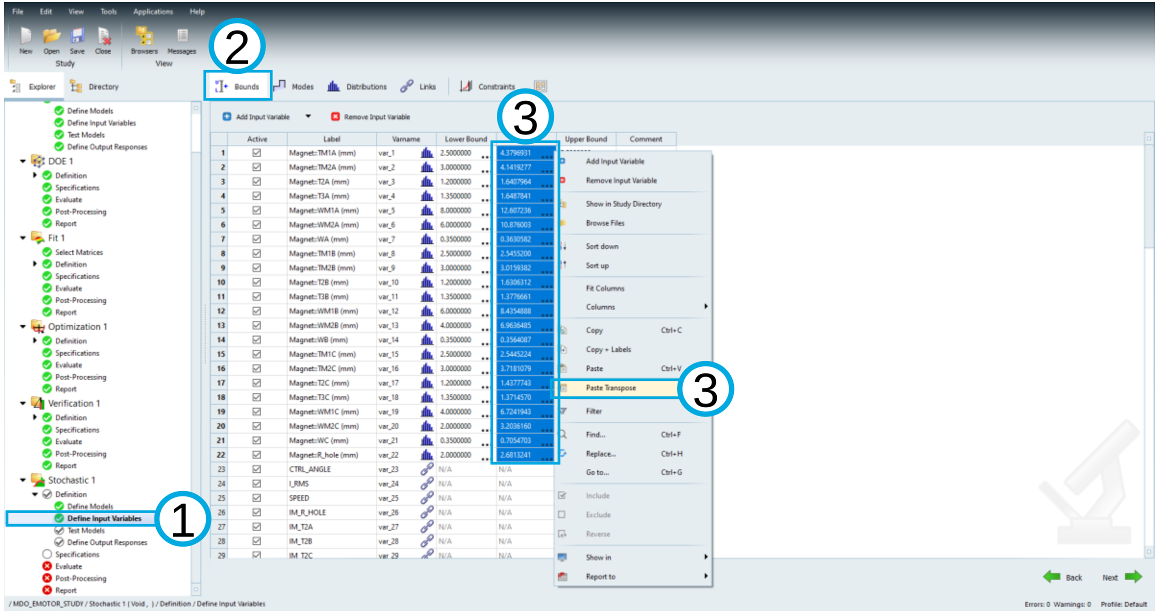
# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Update the parameter values in the stochastic study

| Step | Action |
|---|---|
| 1 | Click on [Stochastic 1] – [Definition] – [Define Input Values] |
| 2 | Click on [Bounds] |
| 3 | Select all the nominal values of the first 22 geometric parameters |
| 4 | Right click and click on [Paste Transpose] |



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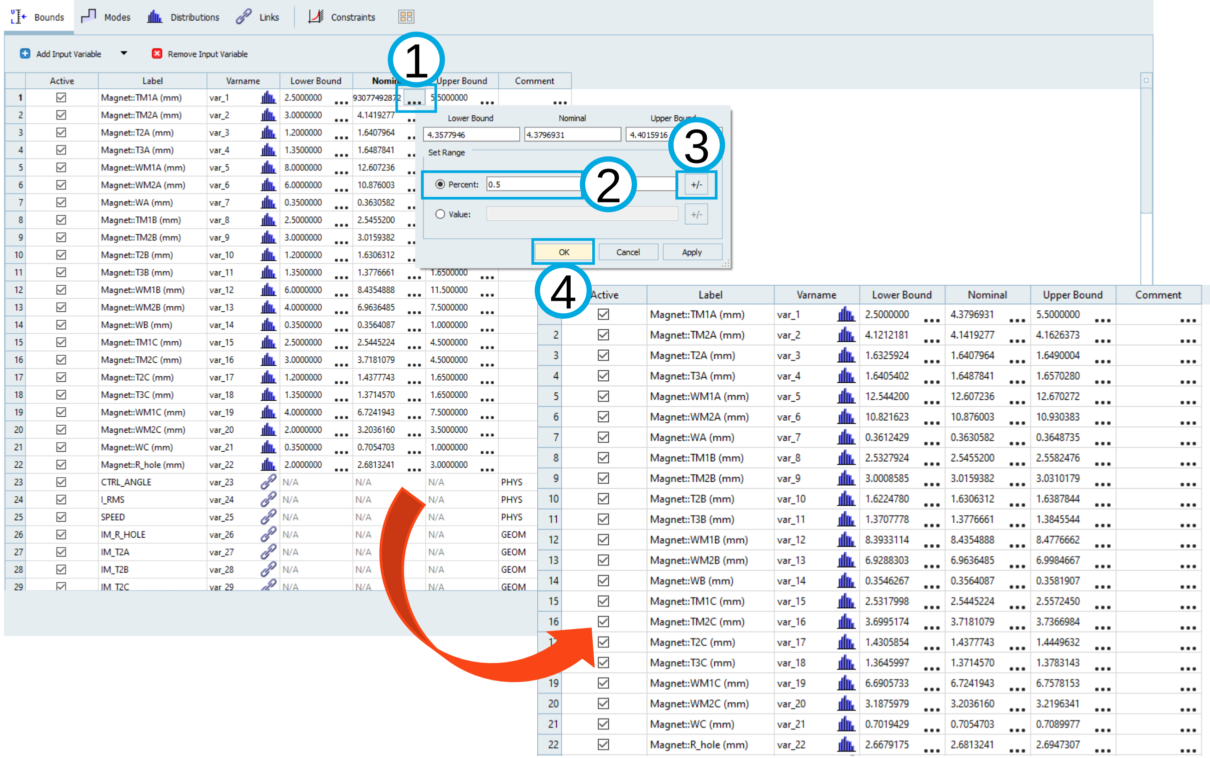
# STOCHASTIC STUDY AND RELIABILITY TEST

Stochastic study initialization

- Define parameter variation

| Step | Action |
|---|---|
| 1 | Click on […] |
| 2 | Define the variation percentage as 0.5% |
| 3 | Click on the icon +/- |
| 4 | Click on [OK] |
| 5 | Change the variation range for all the 22 geometric parameters |



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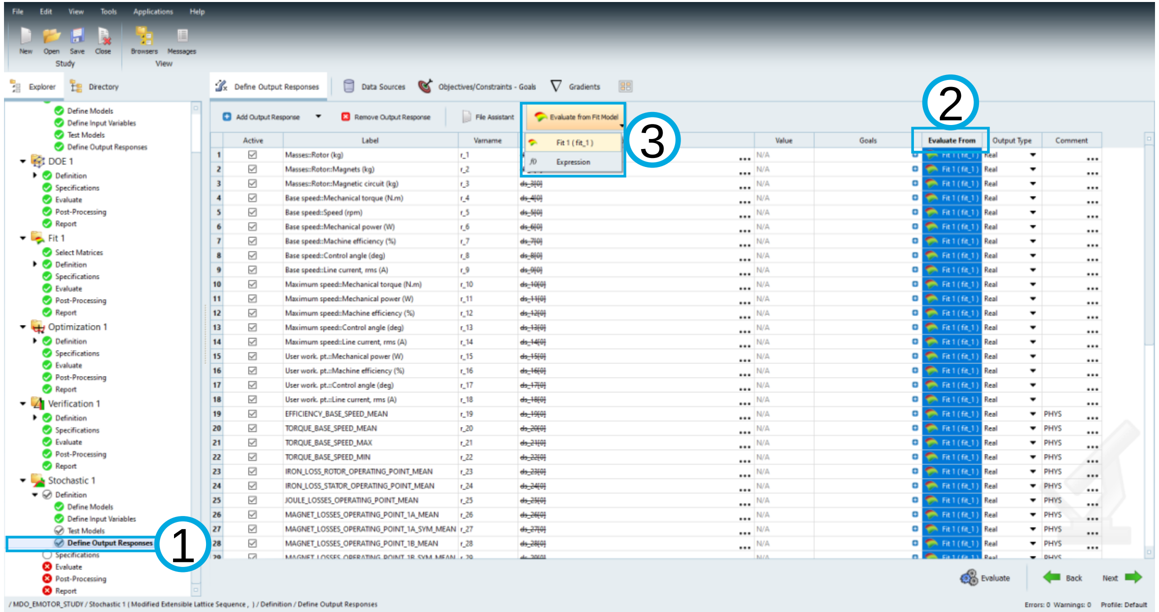
# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Update output responses

| Step | Action |
|---|---|
| 1 | Click on [Stochastic 1] – [Definition] – [Define Output Responses] |
| 2 | Click on [Evaluate From] to select all the output responses |
| 3 | Click on [Evaluate from Fit Model] – [Fit 1] to link the optimization with the fit functions |

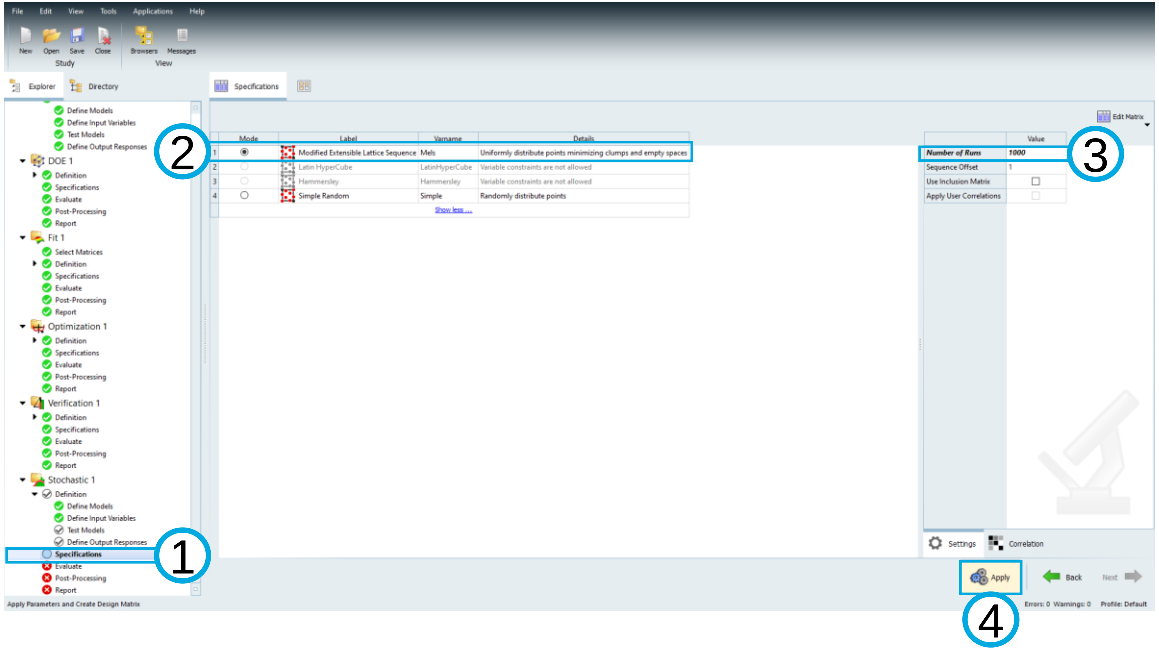


# STOCHASTIC STUDY AND RELIABILITY TEST

Stochastic study evaluation

- Specify the stochastic study

| Step | Action |
|---|---|
| 1 | Click on [Stochastic 1] – [Specification] |
| 2 | Select the method MELS |
| 3 | Define the number of runs as 1000 (by default is 100) |
| 4 | Click on [Apply] |

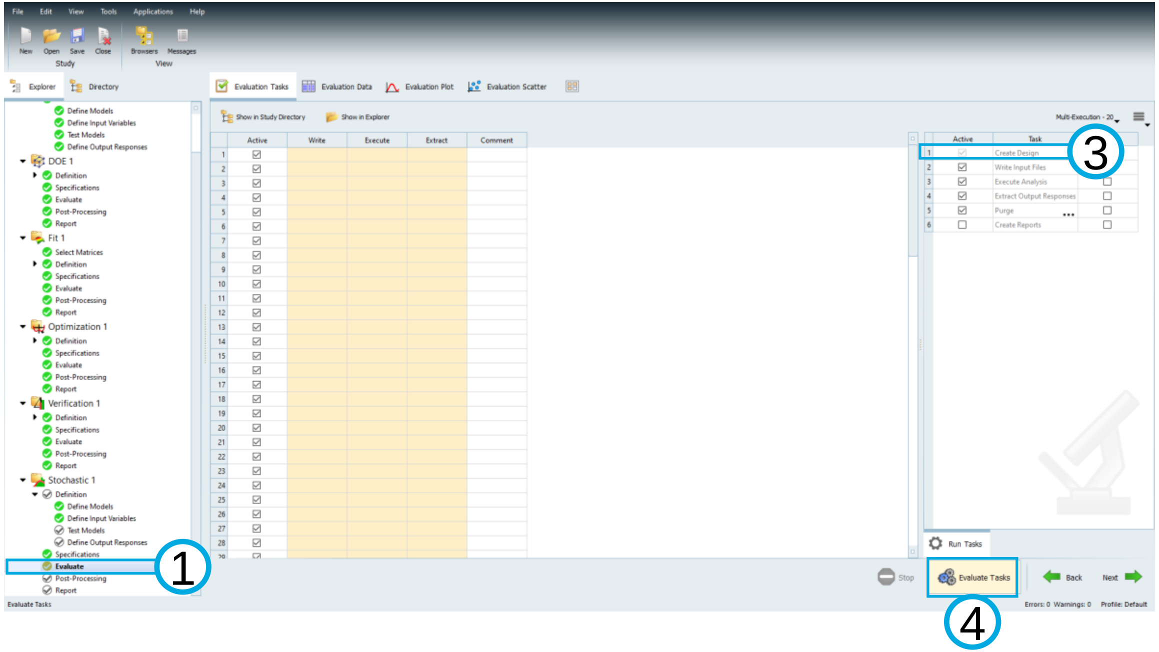


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study evaluation

- Evaluate tasks in stochastic study

| Step | Action |
| --- | --- |
| 1 | Click on [Stochastic 1] – [Specification] |
| 2 | Define the multi-execution number |
| 3 | Click on [Evaluate Tasks] |



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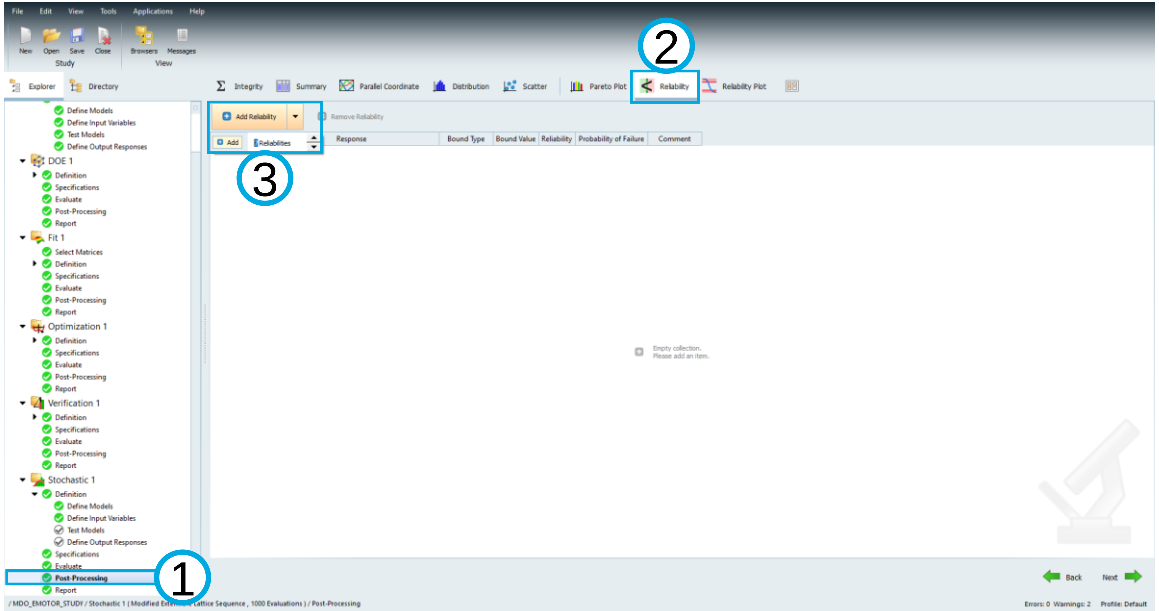
# STOCHASTIC STUDY AND RELIABILITY TEST

Stochastic study post-processing

- Evaluate tasks in stochastic study

| Step | Action |
|---|---|
| 1 | Click on [Stochastic 1] – [Post-Processing] |
| 2 | Click on [Reliability] |
| 3 | Click on [Add Reliability] to add 6 reliability test |

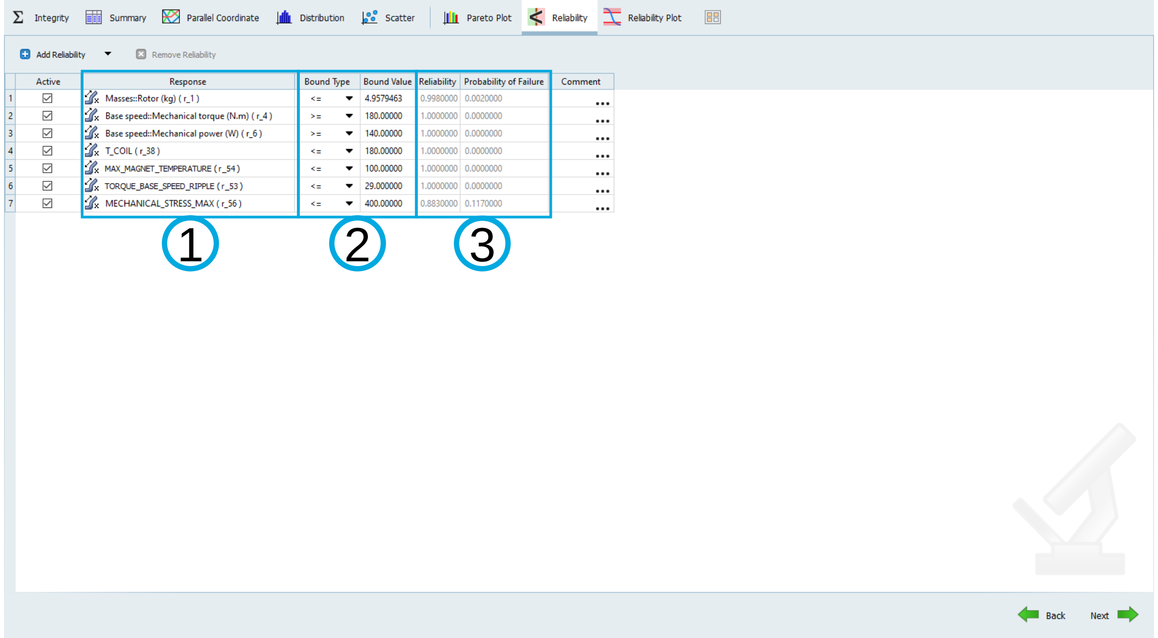


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study post-processing

- Verify the reliabilities of all the objectives

| Step | Action |
|---|---|
| 1 | Define the responses as the optimization objectives |
| 2 | Modify the “Bound Type” and the “Bound Value” |
| 3 | Verify the reliabilities of all the objectives |



# STOCHASTIC STUDY AND RELIABILITY TEST

Stochastic study post-processing

- Verify the reliabilities of all the objectives

| Response | Bound Type | Bound Value | Reliability | Probability of Failure | Comments |
|---|---|---|---|---|---|
| Masses::Rotor (kg) ( r_1 ) | <= | 4.957946 | 0.998 | 0.002 | 99.8% of the optimization results are robust due to a 0.5% parameter variation |
| Base speed::Mechanical torque (N.m) ( r_4 ) | >= | 180 | 1 | 0 | 100% of the optimization results are robust due to a 0.5% parameter variation |
| Base speed::Mechanical power (W) ( r_6 ) | >= | 140 | 1 | 0 | 100% of the optimization results are robust due to a 0.5% parameter variation |
| T_COIL ( r_38 ) | <= | 180 | 1 | 0 | 100% of the optimization results are robust due to a 0.5% parameter variation |
| MAX_MAGNET_TEMPERATURE ( r_54 ) | <= | 100 | 1 | 0 | 100% of the optimization results are robust due to a 0.5% parameter variation |
| TORQUE_BASE_SPEED_RIPPLE ( r_53 ) | <= | 29 | 1 | 0 | 100% of the optimization results are robust due to a 0.5% parameter variation |
| MECHANICAL_STRESS_MAX ( r_56 ) | <= | 400 | 0.883 | 0.117 | 88.3% of the optimization results are robust due to a 0.5% parameter variation |



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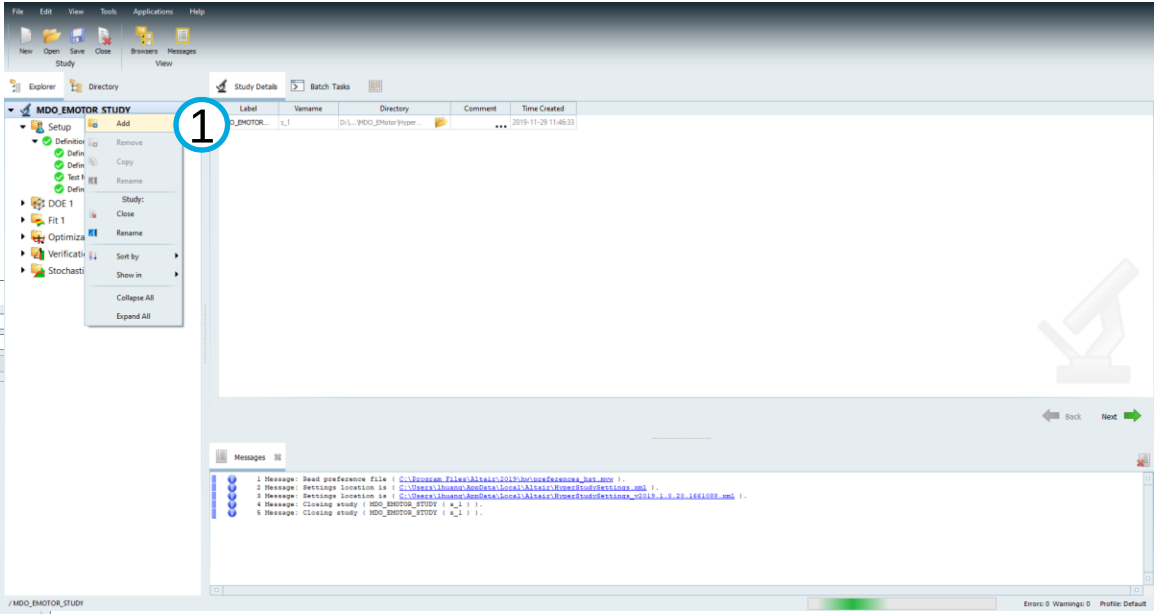
# DIRECT OPTIMIZATION

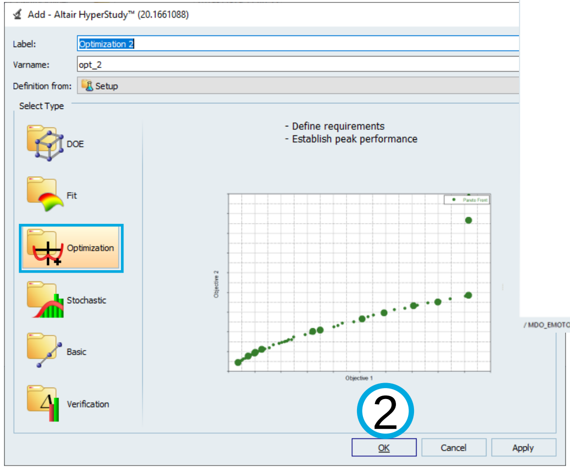
# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Add a new optimization application

| Step | Action |
|---|---|
| 1 | Right click on the project “MDO_MOTOR_STUDY”, click on [Add] |
| 2 | Select the type as “DOE”, click on [OK] |



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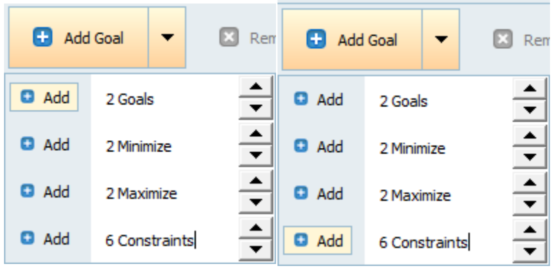
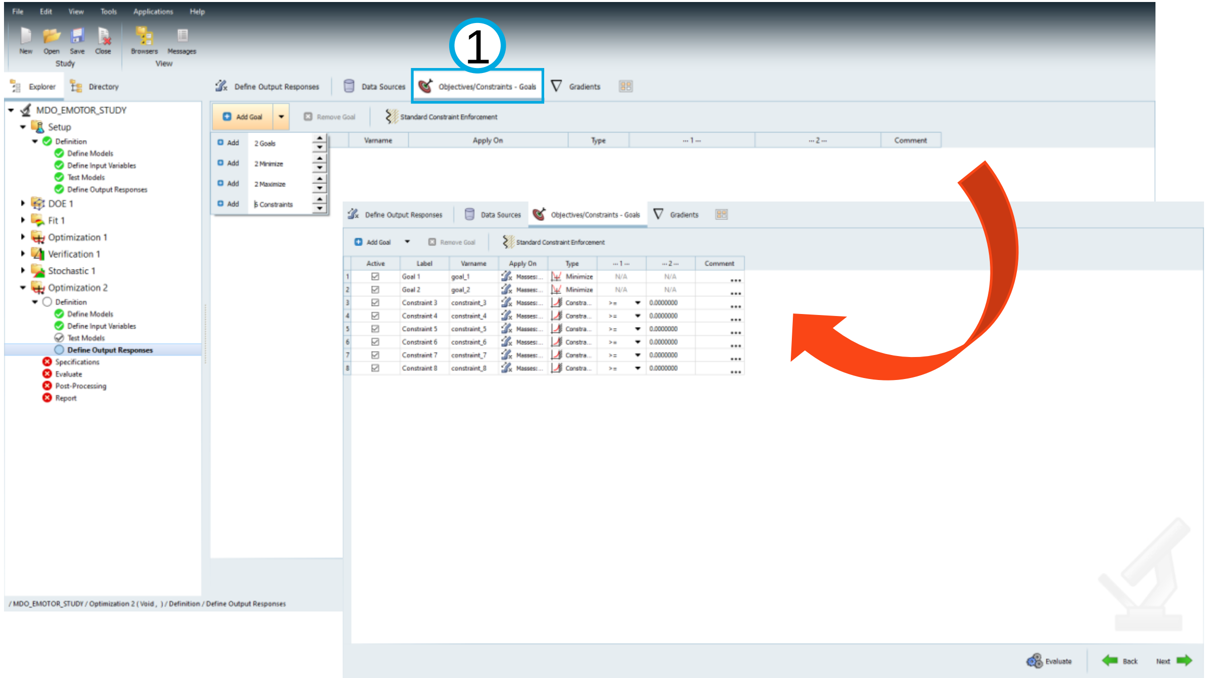
# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

| Step | Action |
|---|---|
| 1 | Click on [Objectives/Constraints - goals] |
| 2 | Click on the icon [Add Goal] to add<br>- 3 Goals<br>- 6 constraints |



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# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

| Step | Action |
|---|---|
| 1 | Modify the goals and constraints as shown in the following table |

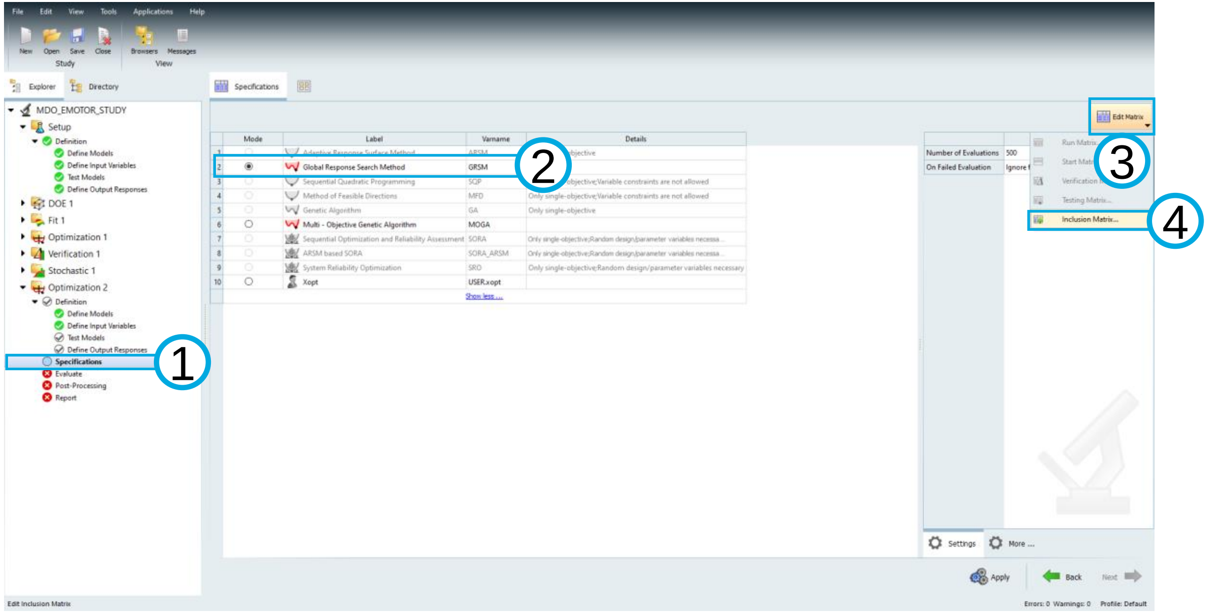
| Label | Varname | Apply on | Type | 1 | 2 |
|---|---|---|---|---|---|
| MaxPowerBaseSpeed | goal_1 | Base speed::Mechanical power (W) ( r_6 ) | Maximize | | |
| MinRotorMass | goal_2 | Masses::Rotor (kg) ( r_1 ) | Minimize | | |
| TorqueBassSpeed | constraint_3 | Base speed::Mechanical torque (N.m) ( r_4 ) | Constraint | >= | 180 |
| PowerBassSpeed | constraint_4 | Base speed::Mechanical power (W) ( r_6 ) | Constraint | >= | 140000 |
| TemperatureWinding | constraint_5 | T_COIL ( r_38 ) | Constraint | <= | 180 |
| TorqueBassSpeedRipple | constraint_6 | TORQUE_BASE_SPEED_RIPPLE ( r_53 ) | Constraint | <= | 29 |
| TempMagnetMax | constraint_7 | MAX_MAGNET_TEMPERATURE ( r_54 ) | Constraint | <= | 100 |
| MechanicalStress | constraint_8 | MECHANICAL_STRESS_MAX ( r_56 ) | Constraint | <= | 400 |

# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

| Step | Action |
|---|---|
| 1 | Click on [Optimization 2] – [Specifications] |
| 2 | Select “GRSM” algorithm |
| 3 | Click on [Edit Matrix] |
| 4 | Click on [Inclusion Matrix] |




*Note: The Multi Objective Generic Algorithm is a suitable method for the optimization problem based on fit functions.*



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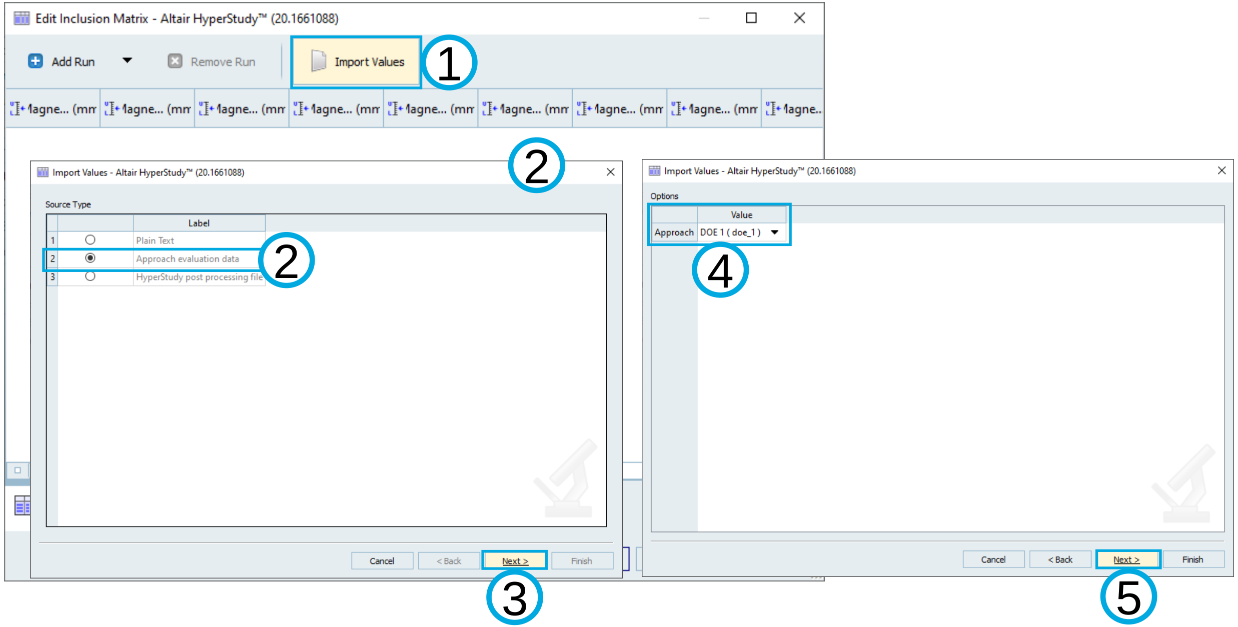
# DIRECT OPTIMIZATION PROCESS

Optimization initialization

- Define optimization setting – import matrix from DOE

| Step | Action |
|---|---|
| 1 | Click on [Import Values] |
| 2 | Select "Approach evaluation data" |
| 3 | Click on [Next] |
| 4 | Select on the [DOE 1] as the approach |
| 5 | Click on [Next] |

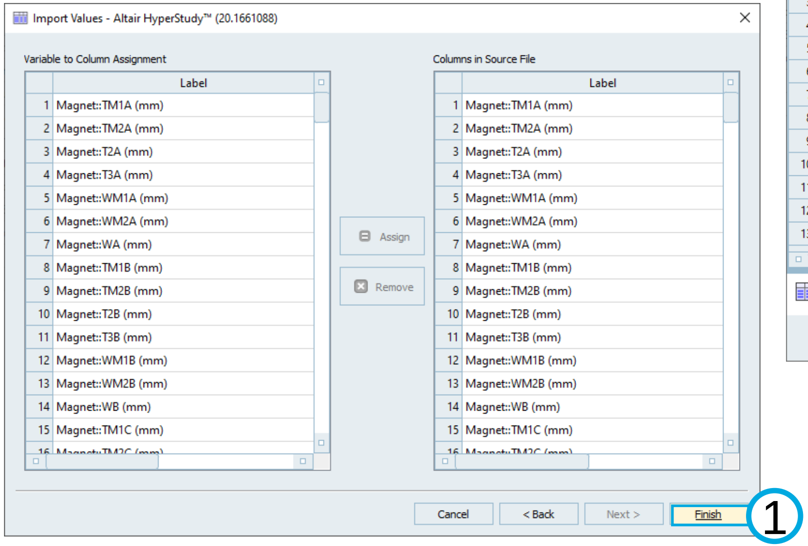


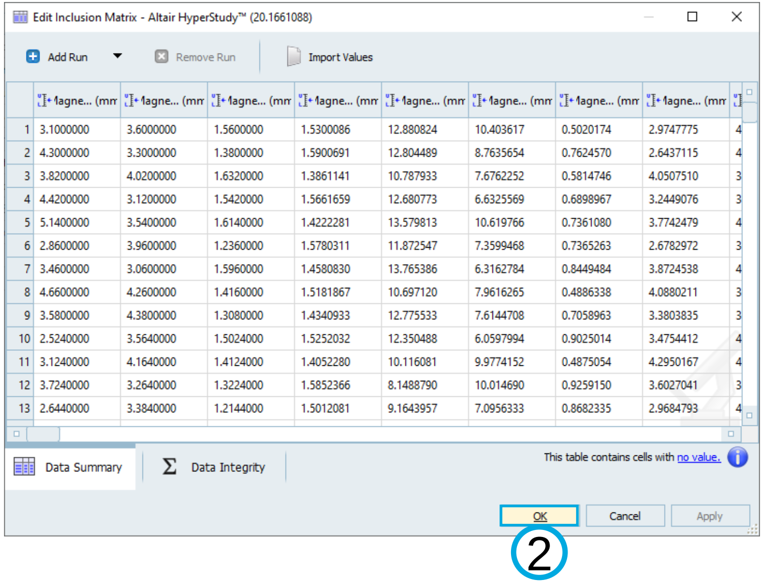
# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

| Step | Action |
|---|---|
| 1 | Click on [Finish] |
| 2 | Click on [OK] |



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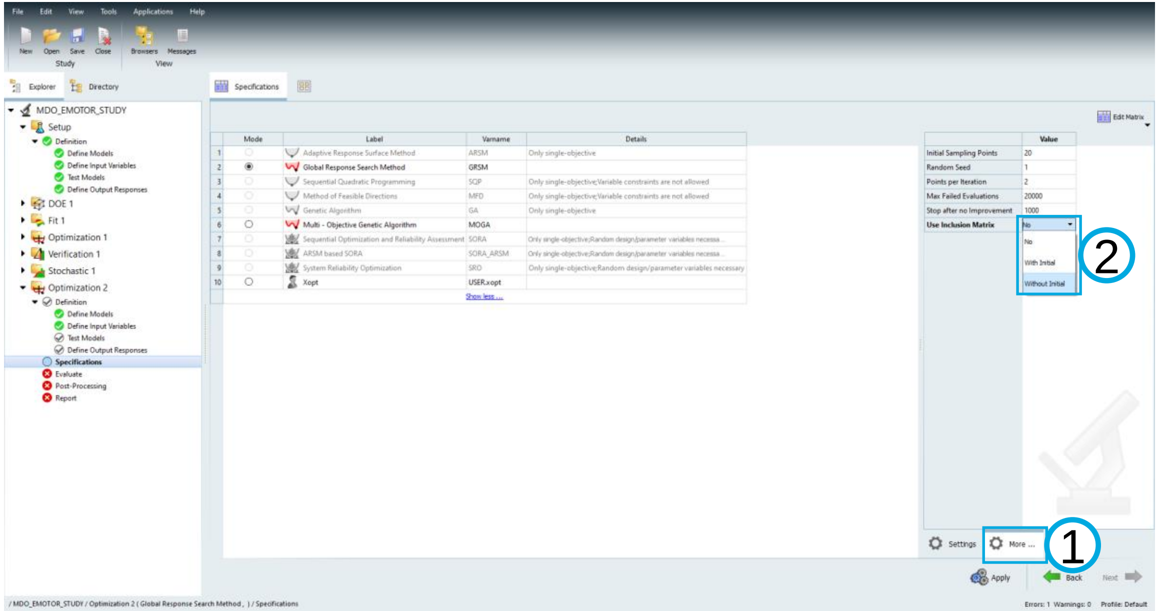
# DIRECT OPTIMIZATION PROCESS

Optimization initialization

- Define optimization setting – import matrix from DOE

| Step | Action |
| --- | --- |
| 1 | Click on [More] |
| 2 | Select “Without Initial” |



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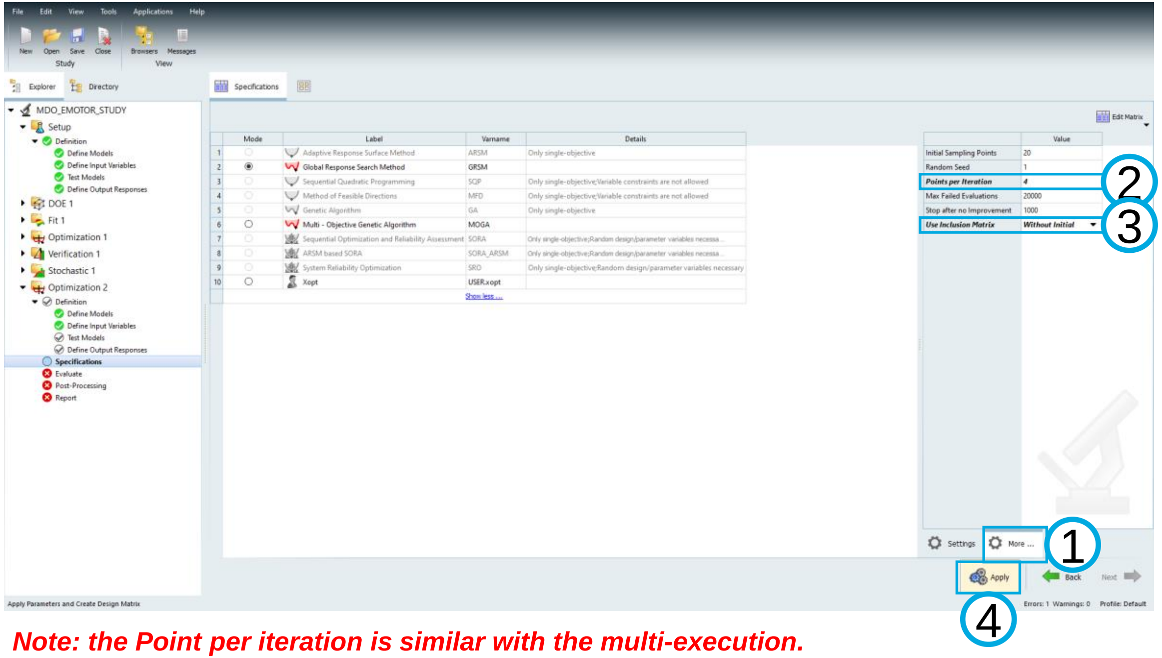
# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

| Step | Action |
|---|---|
| 1 | Click on [More] |
| 2 | Define the “Point per iteration” |
| 3 | Select “Without Initial” |



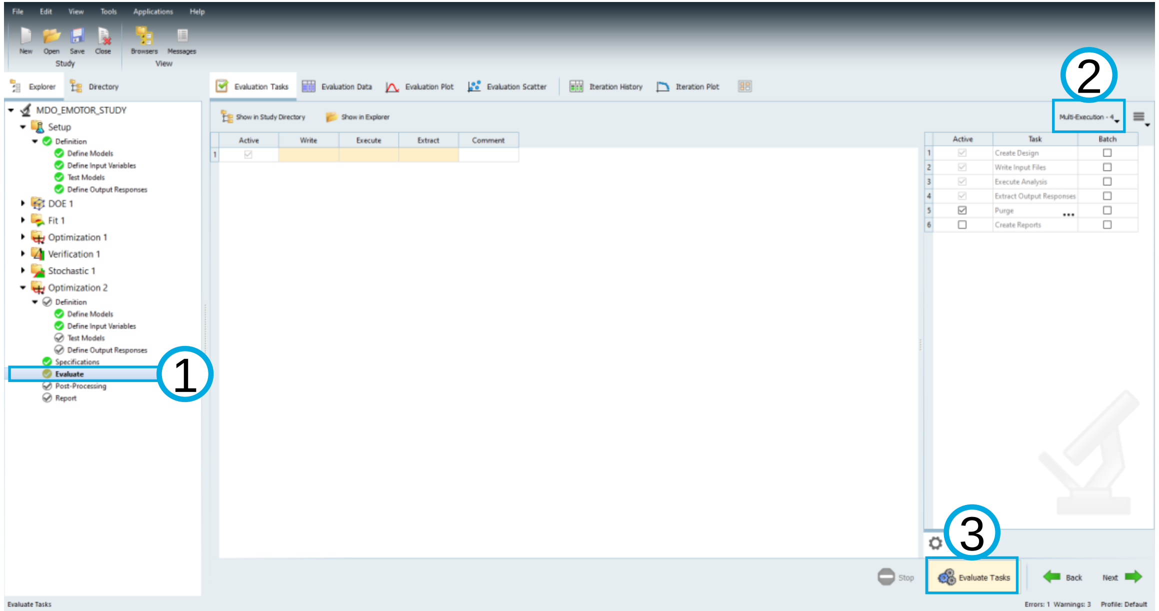

***Note: the Point per iteration is similar with the multi-execution.***

# DIRECT OPTIMIZATION PROCESS

Optimization evaluation

- Evaluate tasks for the optimization problem

| Step | Action |
|---|---|
| 1 | Click on [Optimization 2] – [Evaluate] |
| 2 | Define the “multi-execution” number as the same as the “Point per iteration” |
| 3 | Click on [Evaluate Tasks] |



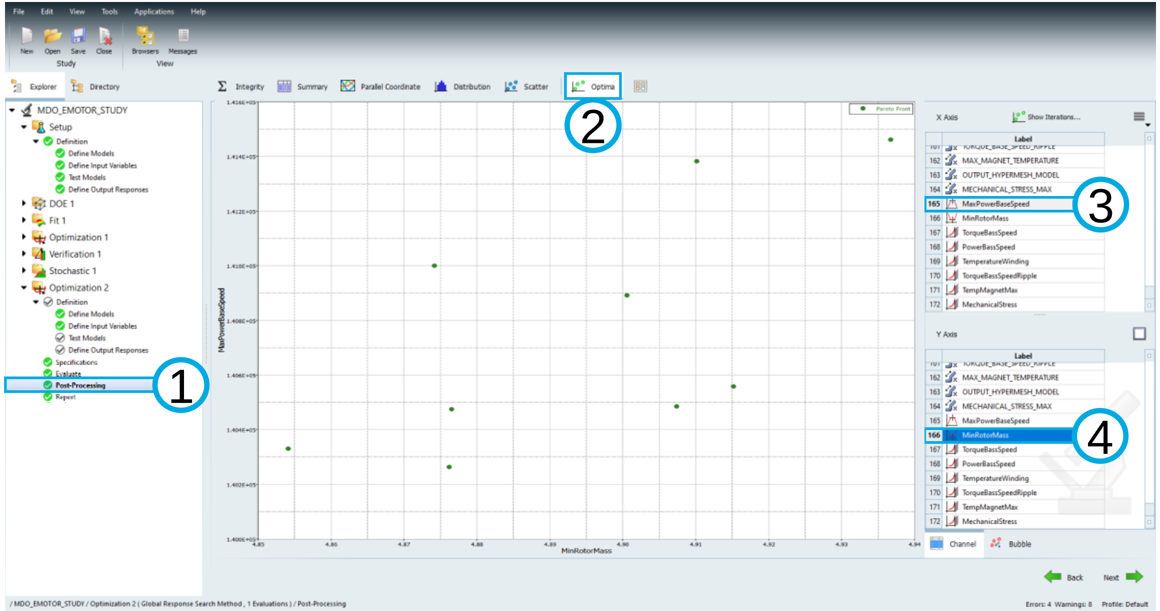

*Note: The optimization problem based on fit functions will cost as the same time as DOE analysis*

# DIRECT OPTIMIZATION PROCESS

Optimization post-processing

- Plot optimal curve

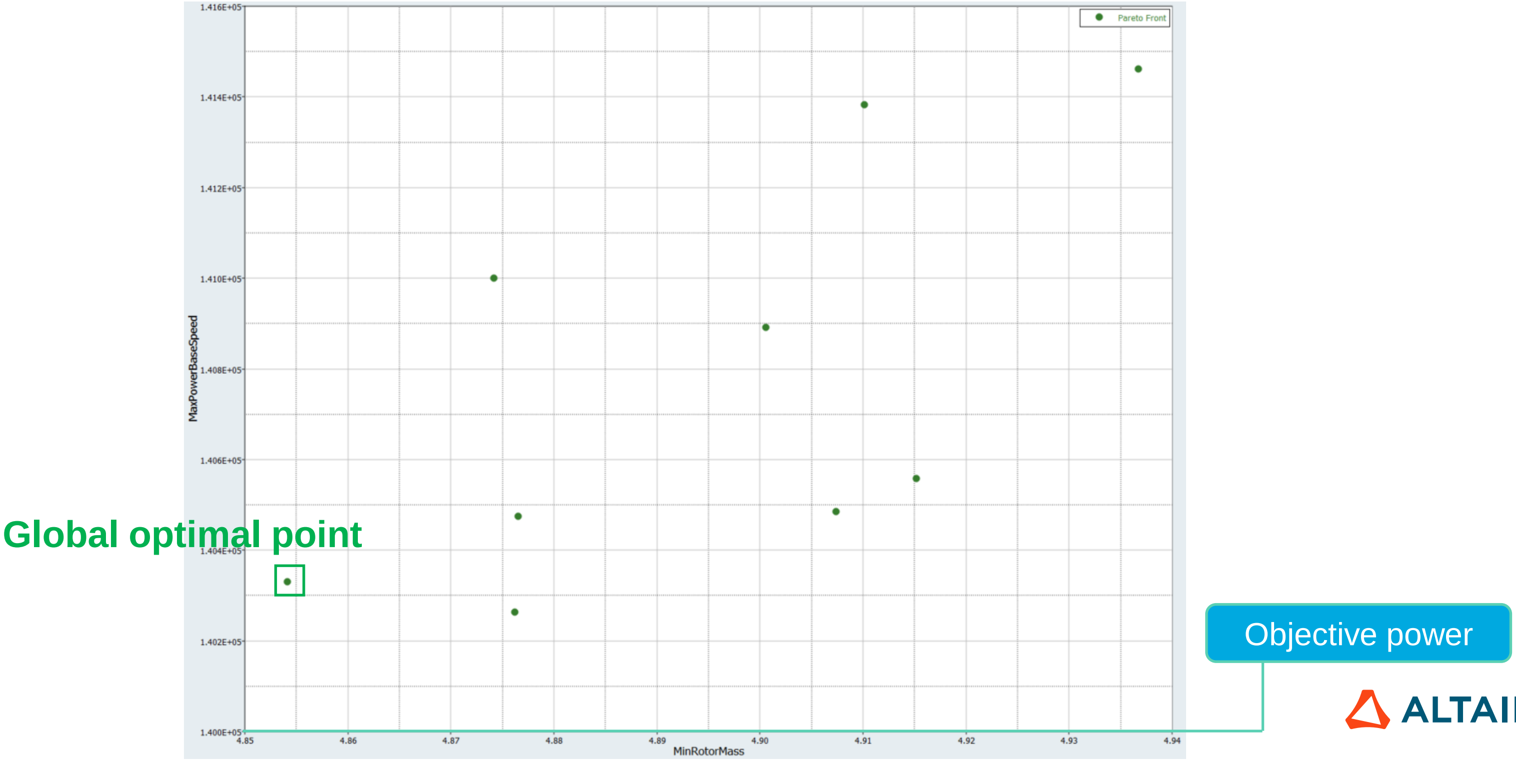
| Step | Action |
|---|---|
| 1 | Click on [Post-Processing] |
| 2 | Click on [Optimal] to see all the optimization results for the electric motor |
| 3 | Select the Goal "MinRotorMass" |
| 4 | Select the Goal "MaxPowerBaseSpeed" |



# DIRECT OPTIMIZATION PROCESS

Optimization result comparison

- Global optimal results



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# DIRECT OPTIMIZATION PROCESS

Optimization result comparison

- Global optimal results (between direction optimization method and fit function based optimization)

| | Original value | Fit function based optimization | Direction optimization method |
|---|---|---|---|
| Mechanical power at base point / W | 137818 | **140854.7** | 140329.76 |
| Rotor mass / kg | 4.96 | **4.85** | **4.85** |
| Mechanical torque at base point / N*m | 184.21 | 181.43 | **180.49** |
| Mechanical torque ripple at base point / N*m | 43.11 | 34.78 | **28.46** |
| Winding temperature / °C | 151.01 | 159.37 | **157.59** |
| Magnet temperature / °C | 46.75 | 46.11 | **45.88** |
| Mechanical stress / MPa | 450.79 | **390.80** | 396.23 |



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# CONCLUSION

# CONCLUSION

Both direction optimization method and fit function based optimization have been used and tested in the MDO platform

Both the optimum found by the two method fulfilling all criteria

The fit function based optimization can save more time in the optimization part

# THANK YOU

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#ONLYFORWARD