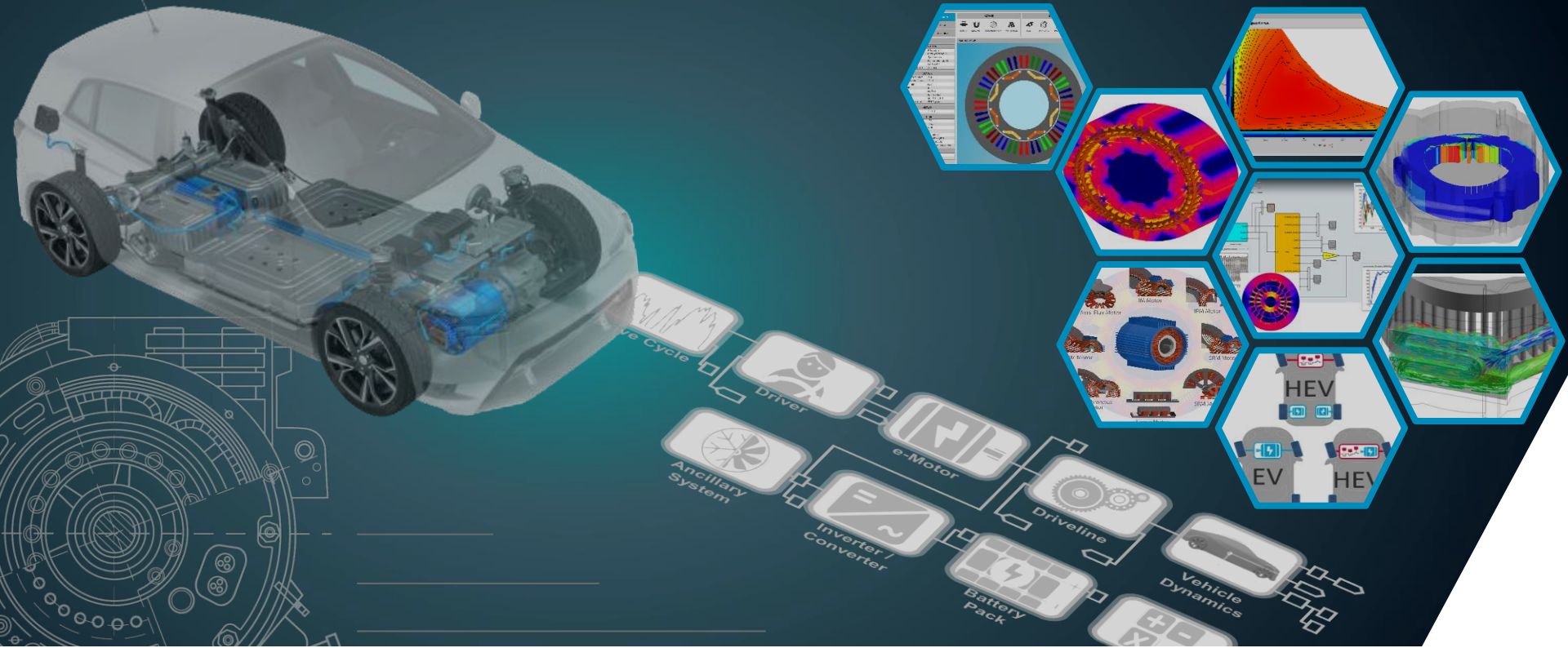


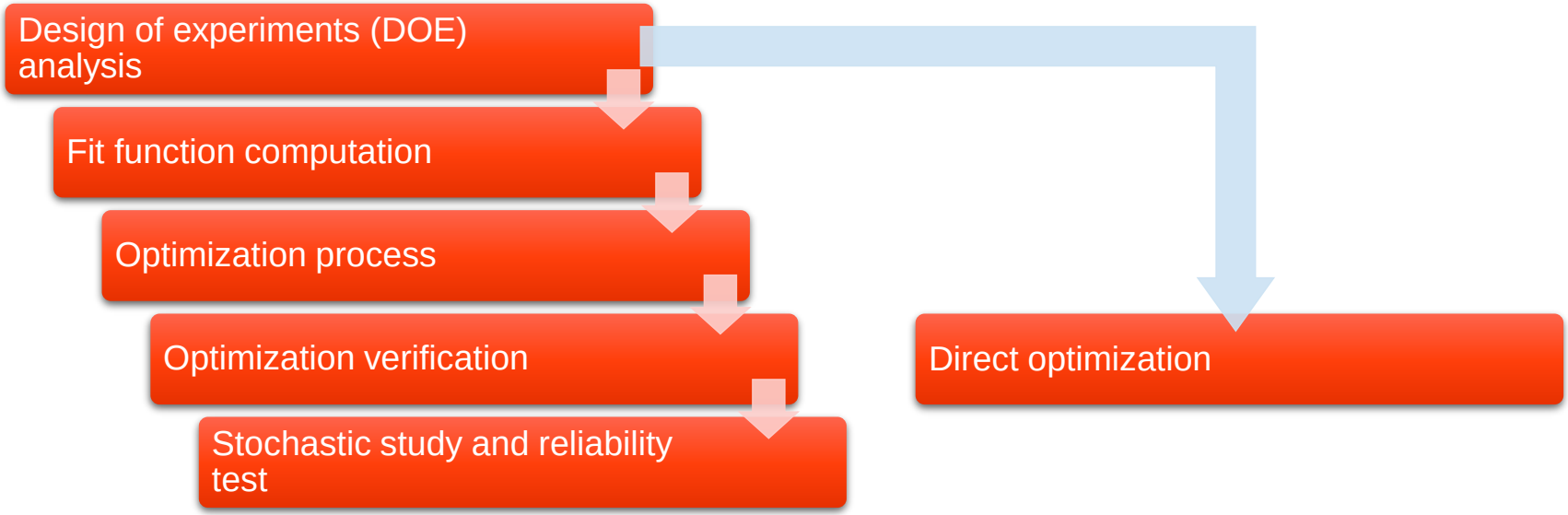
HYPERSTUDY: MULTIDISCIPLINARY DESIGN OPTIMIZATION PROCESS

ALTAIR MULTIDISCIPLINARY DESIGN OPTIMIZATION PLATFORM FOR ELECTRIC MOTORS

November 2021, Altair Flux / FluxMotor Valorization and Support Team

OUTLINE

- Two optimization workflow are available in HyperStudy
  - Optimization based on fit functions
  - Direct optimization method



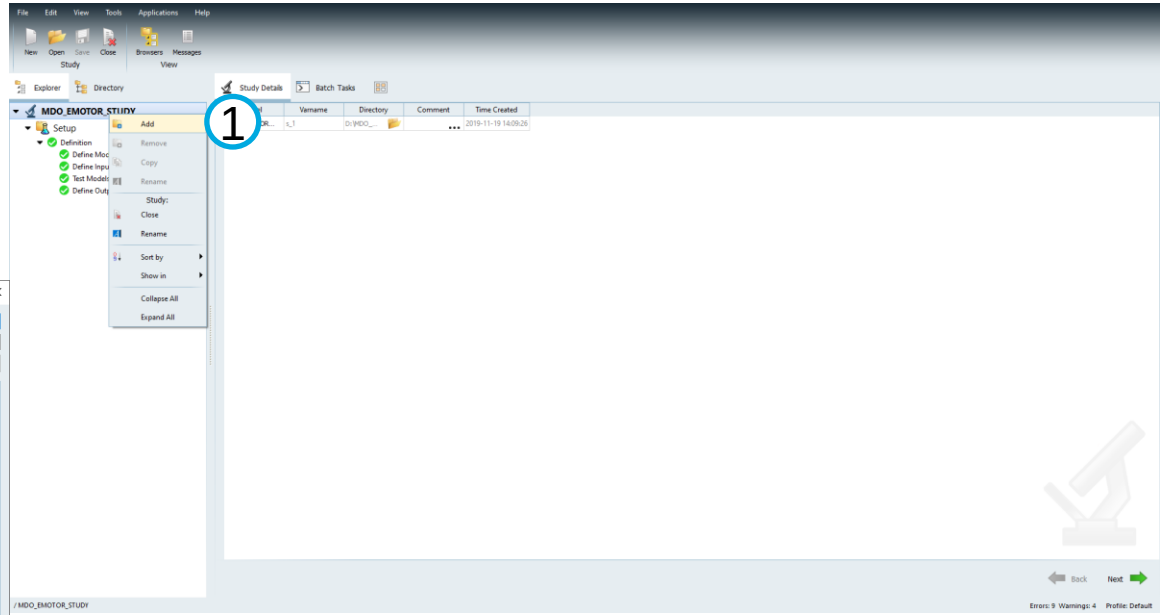
OPTIMIZATION BASED ON FIT FUNCTIONS

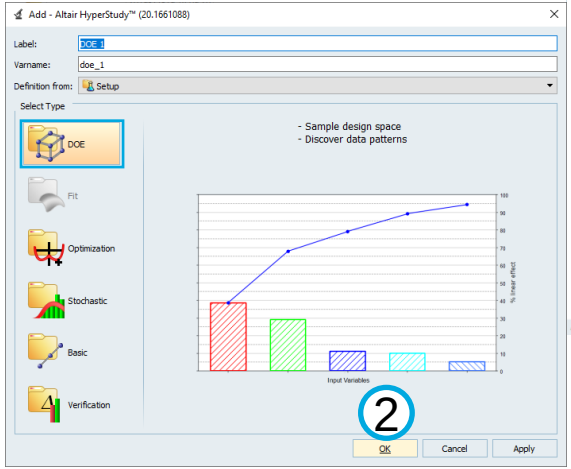
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

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]

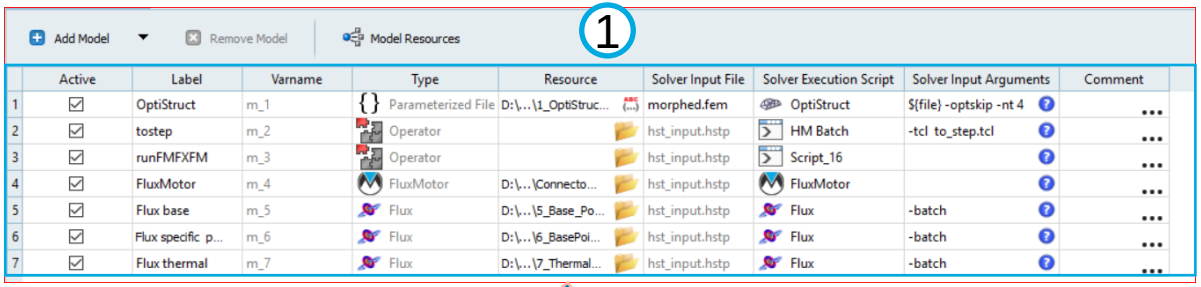


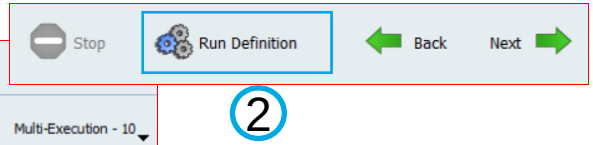


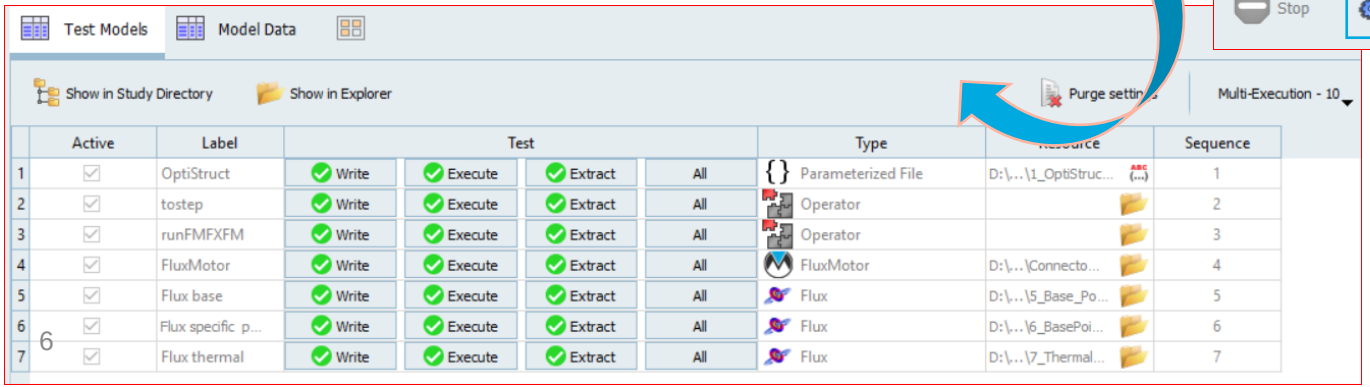
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- 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



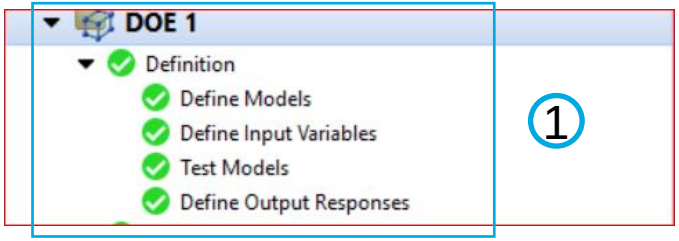


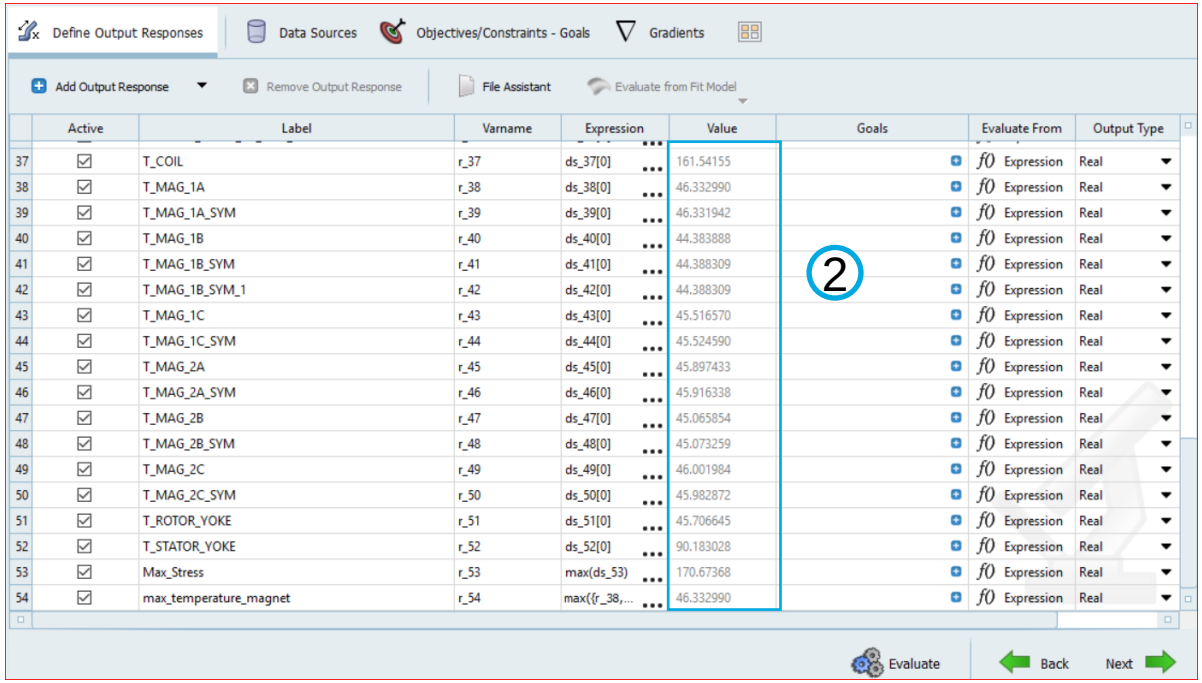


DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- 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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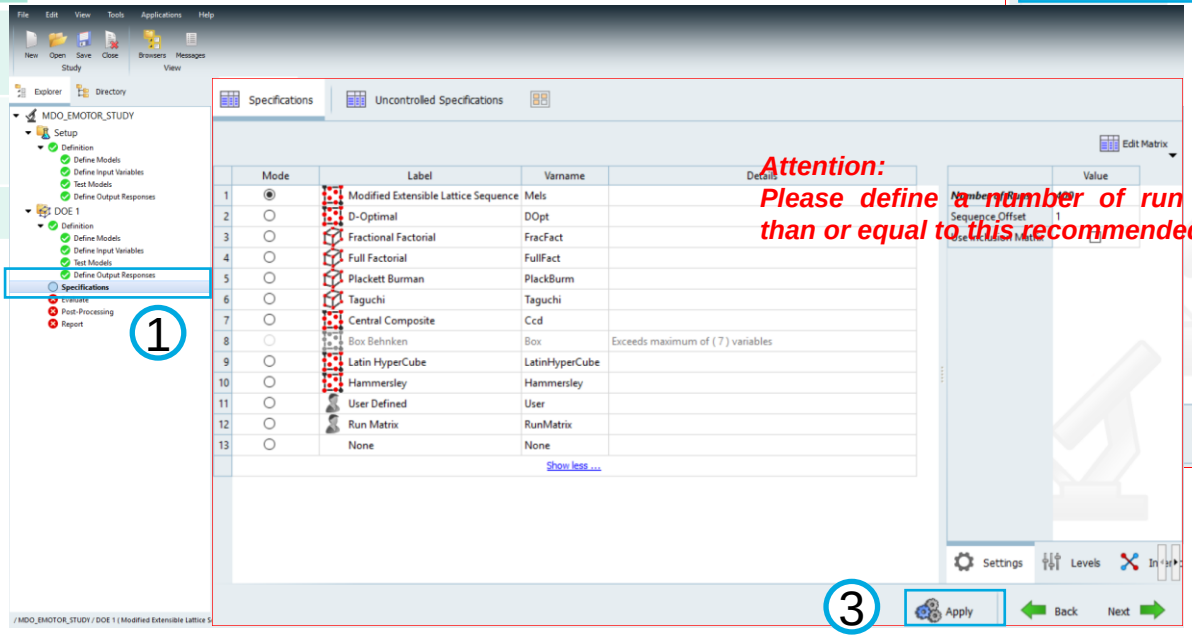
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- 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]



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DESIGN OF EXPERIMENTS (DOE) ANALYSIS

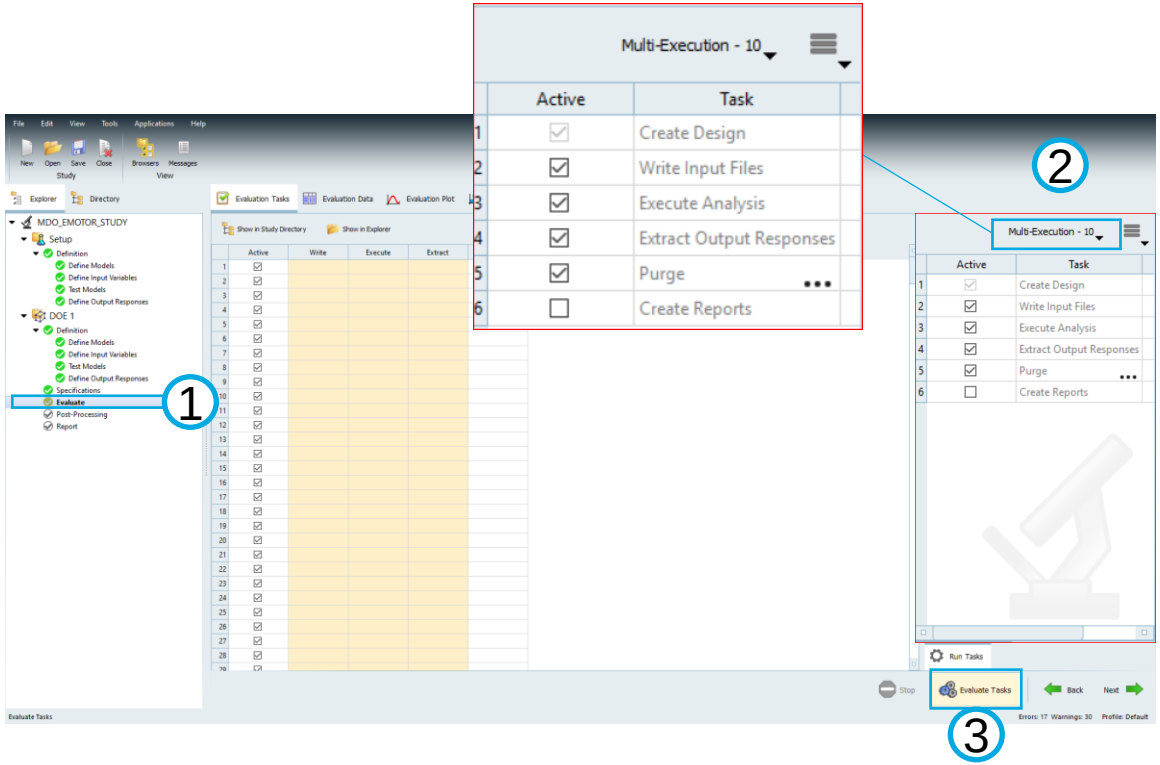
- DOE analysis evaluation
  - Evaluate DOE tasks

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: **400***
*Number of multi-excution: **10***

*Computation time is **21** hours*



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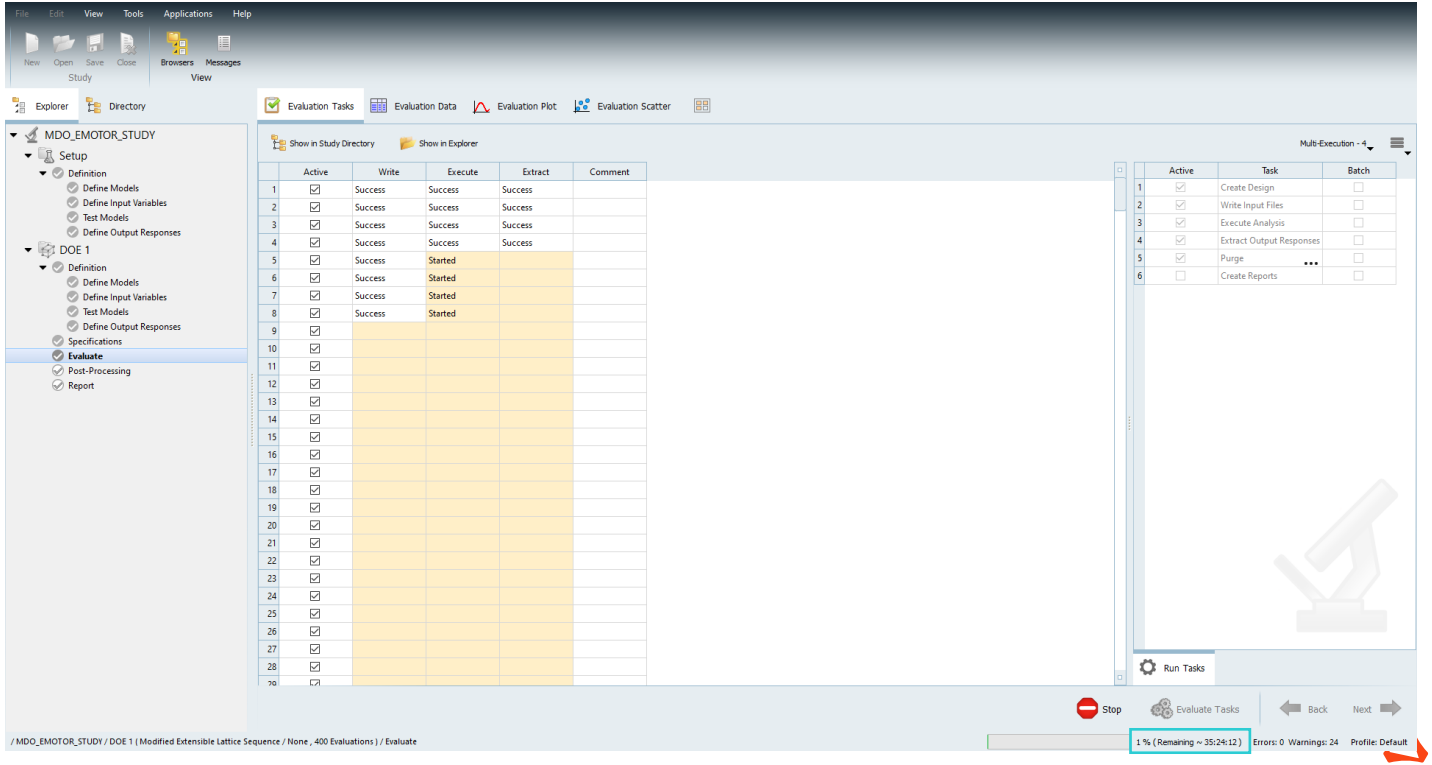
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- Evaluate tasks in DOE analysis



Estimated computation time

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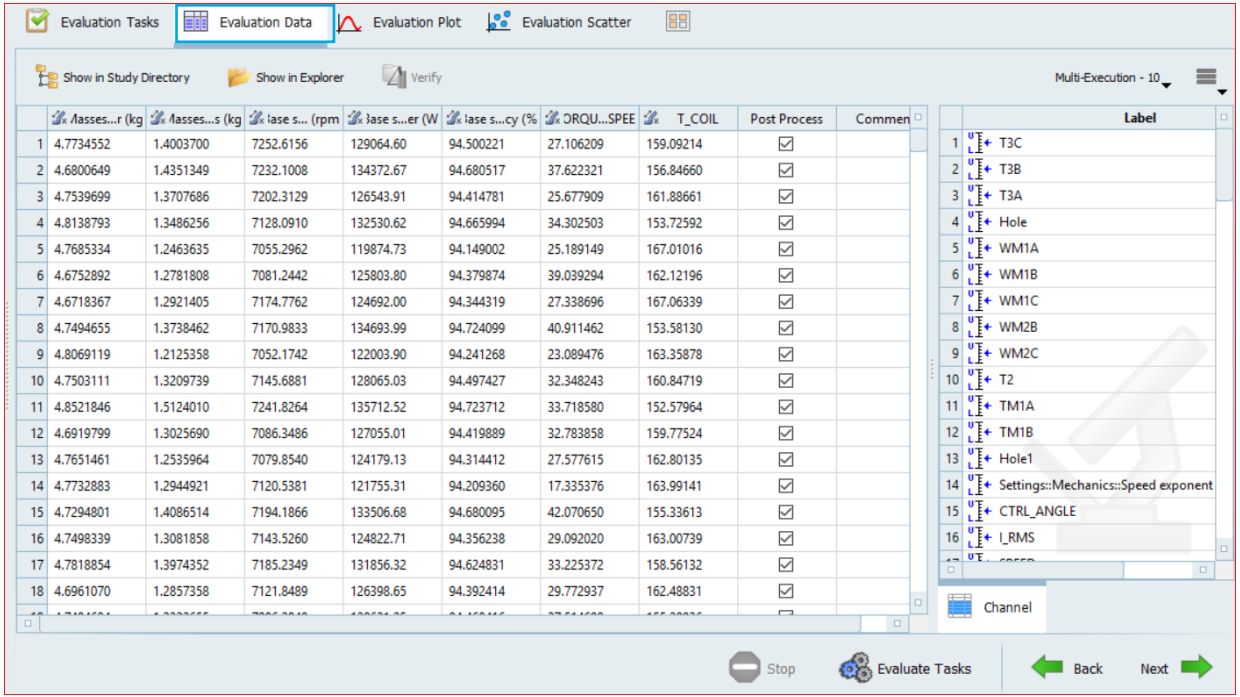
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- DOE analysis evaluation
  - View DOE analysis results

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



	Masses...r (kg	Masses...s (kg	Base s... (rpm	Base s...er (W	Base s...cy (%	TORQU...SPEE	T_COIL	Post Process	Commen
1	4.7734552	1.4003700	7252.6156	129064.60	94.500221	27.106209	159.09214	☑	
2	4.6800649	1.4351349	7232.1008	134372.67	94.680517	37.622321	156.84660	☑	
3	4.7539699	1.3707686	7202.3129	126543.91	94.414781	25.677909	161.88661	☑	
4	4.8138793	1.3486256	7128.0910	132530.62	94.665994	34.302503	153.72592	☑	
5	4.7685334	1.2463635	7055.2962	119874.73	94.149002	25.189149	167.01016	☑	
6	4.6752892	1.2781808	7081.2442	125803.80	94.379874	39.039294	162.12196	☑	
7	4.6718367	1.2921405	7174.7762	124692.00	94.344319	27.338696	167.06339	☑	
8	4.7494655	1.3738462	7170.9833	134693.99	94.724099	40.911462	153.58130	☑	
9	4.8069119	1.2125358	7052.1742	122003.90	94.241268	23.089476	163.35878	☑	
10	4.7503111	1.3209739	7145.6881	128065.03	94.497427	32.348243	160.84719	☑	
11	4.8521846	1.5124010	7241.8264	135712.52	94.723712	33.718580	152.57964	☑	
12	4.6919799	1.3025690	7086.3486	127055.01	94.419889	32.783858	159.77524	☑	
13	4.7651461	1.2535964	7079.8540	124179.13	94.314412	27.577615	162.80135	☑	
14	4.7732883	1.2944921	7120.5381	121755.31	94.209360	17.335376	163.99141	☑	
15	4.7294801	1.4086514	7194.1866	133506.68	94.680095	42.070650	155.33613	☑	
16	4.7498339	1.3081858	7143.5260	124822.71	94.356238	29.092020	163.00739	☑	
17	4.7818854	1.3974352	7185.2349	131856.32	94.624831	33.225372	158.56132	☑	
18	4.6961070	1.2857358	7121.8489	126398.65	94.392414	29.772937	162.48831	☑	

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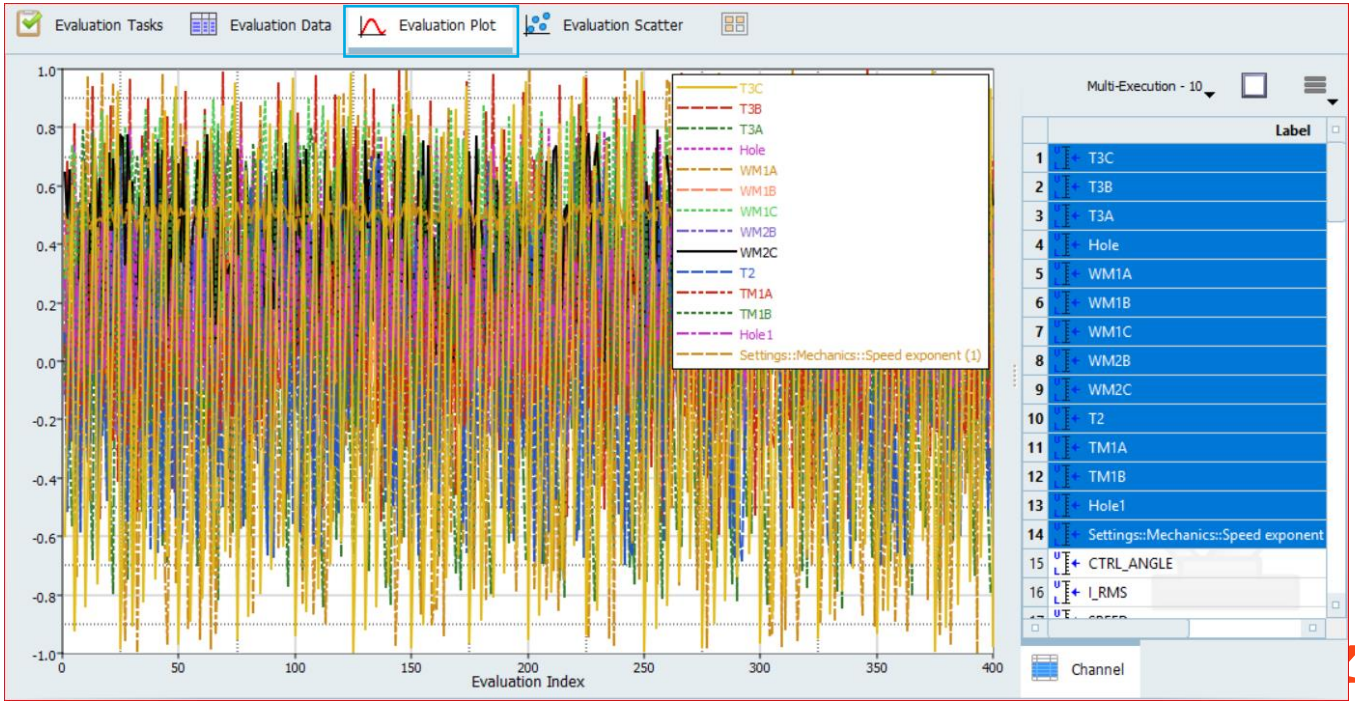
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- DOE analysis evaluation
  - View DOE analysis results

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



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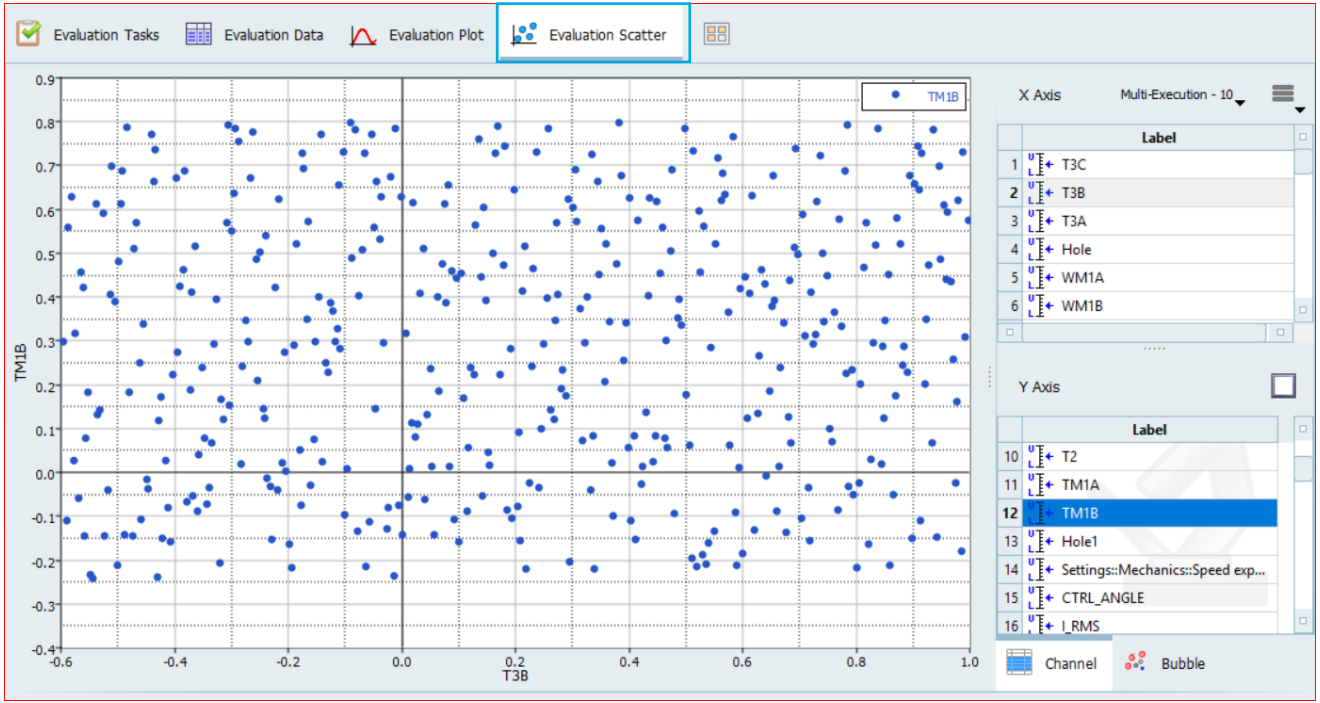
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- DOE analysis evaluation
  - View DOE analysis results

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



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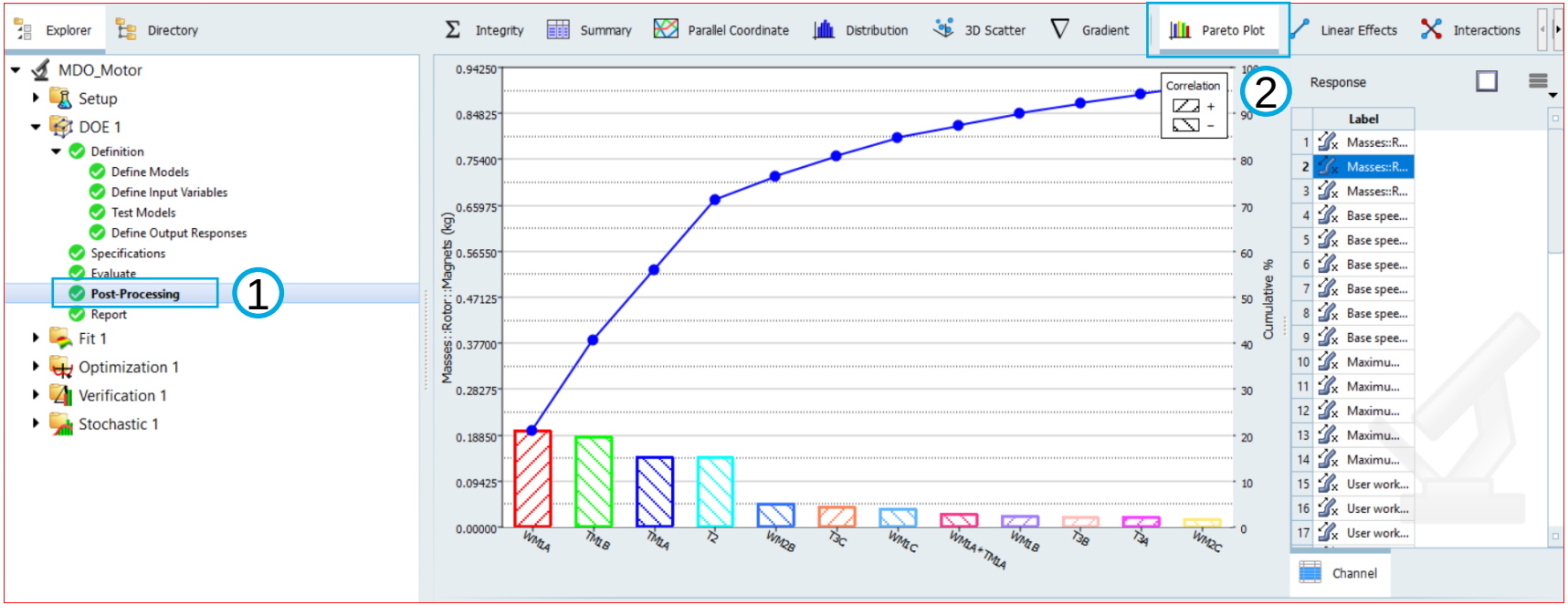
DESIGN OF EXPERIMENTS (DOE) ANALYSIS

- 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

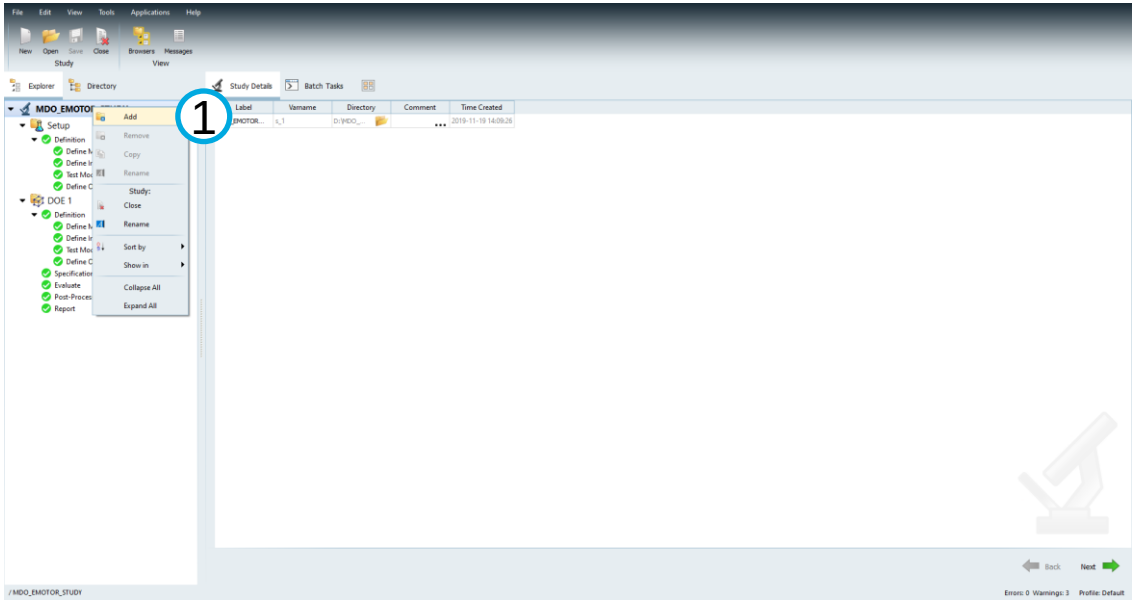


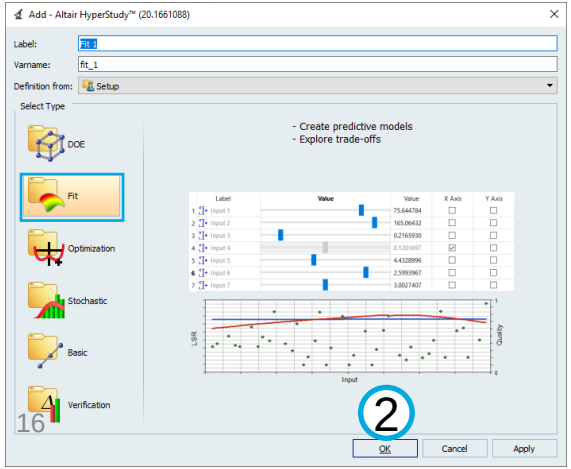
FIT FUNCTION COMPUTATION

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]

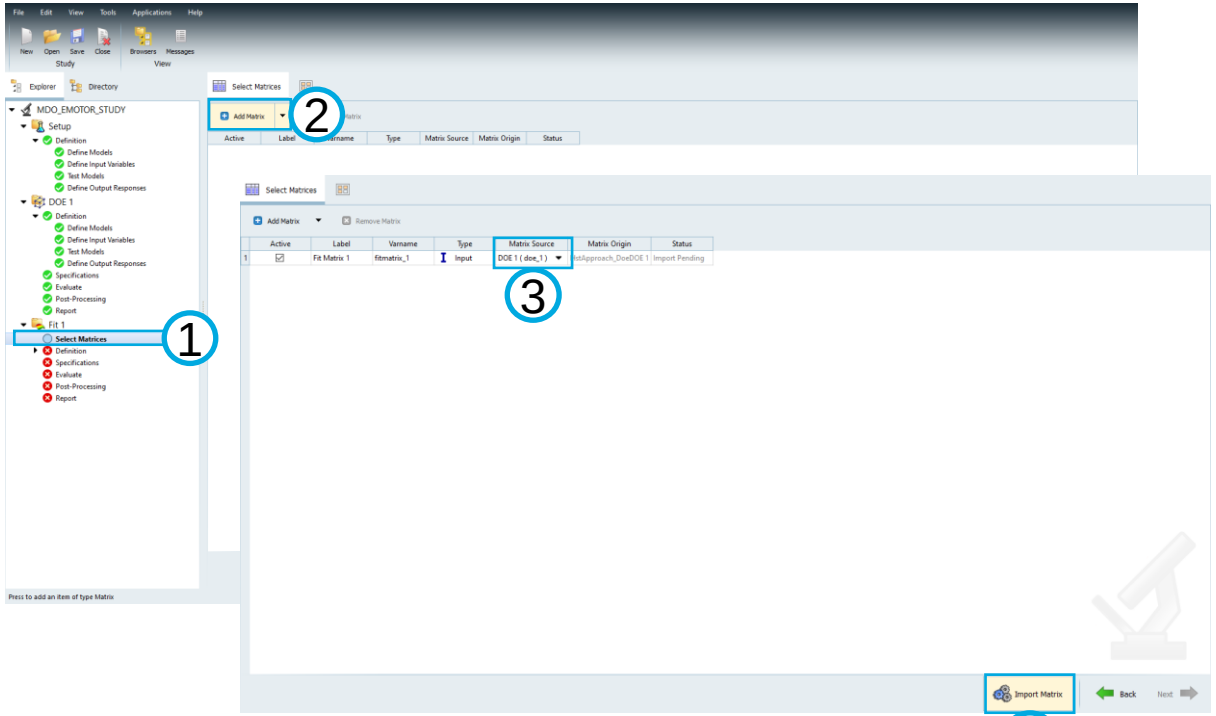




FIT FUNCTION COMPUTATION

- 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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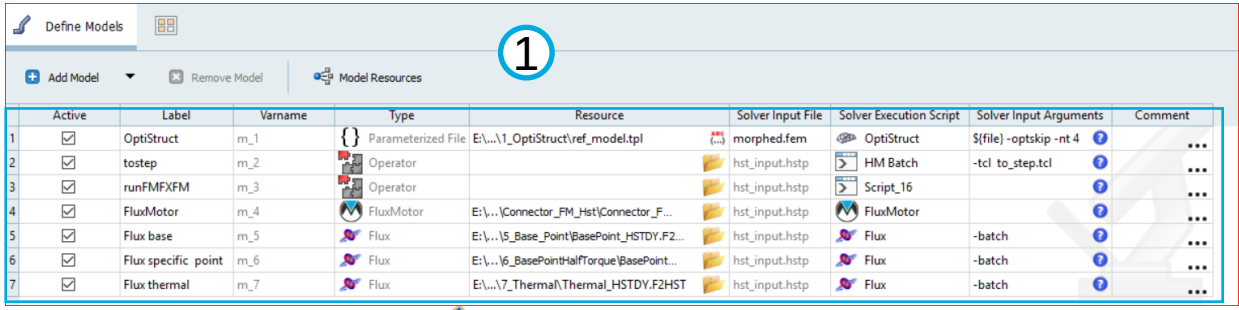
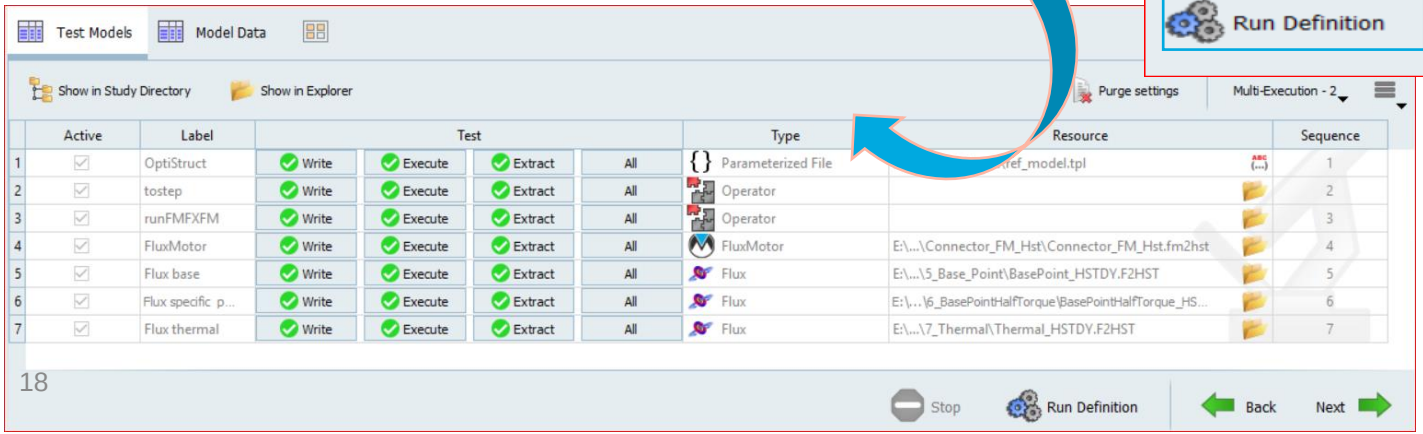
FIT FUNCTION COMPUTATION

- 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





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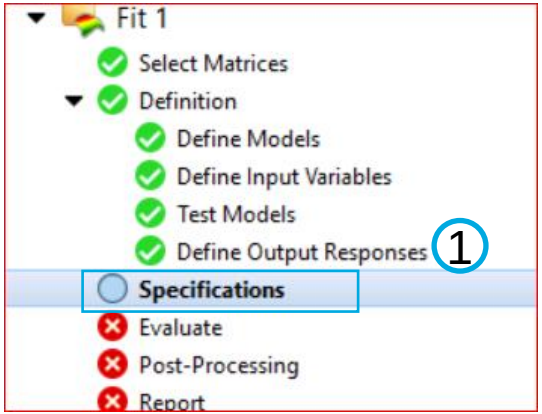
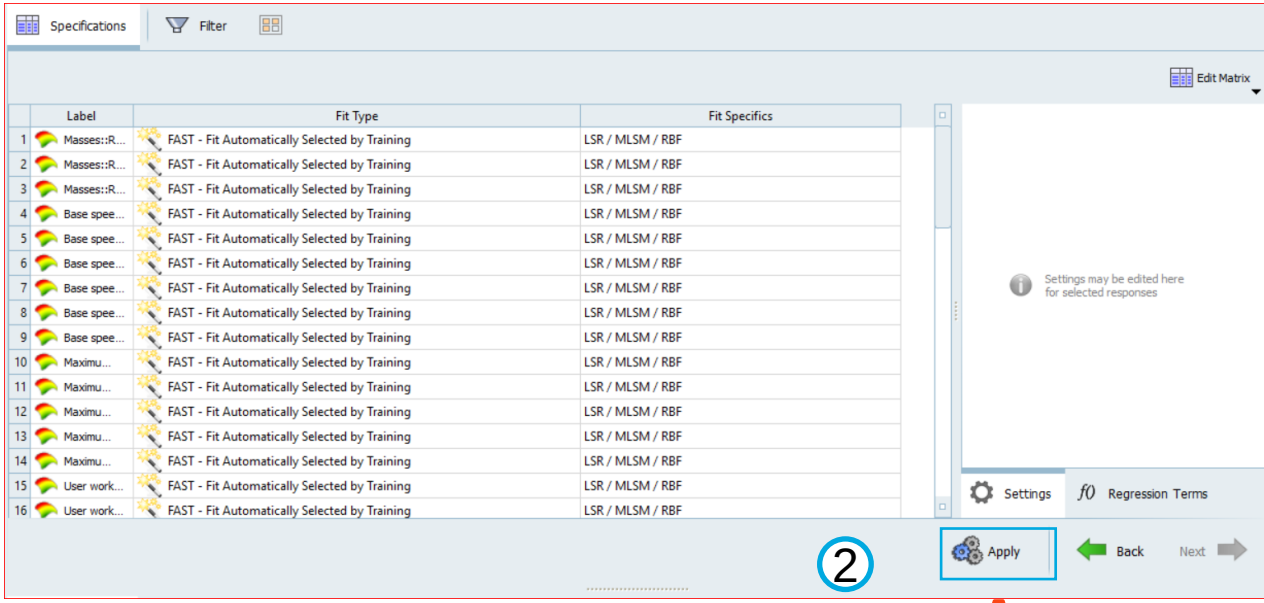
FIT FUNCTION COMPUTATION

- 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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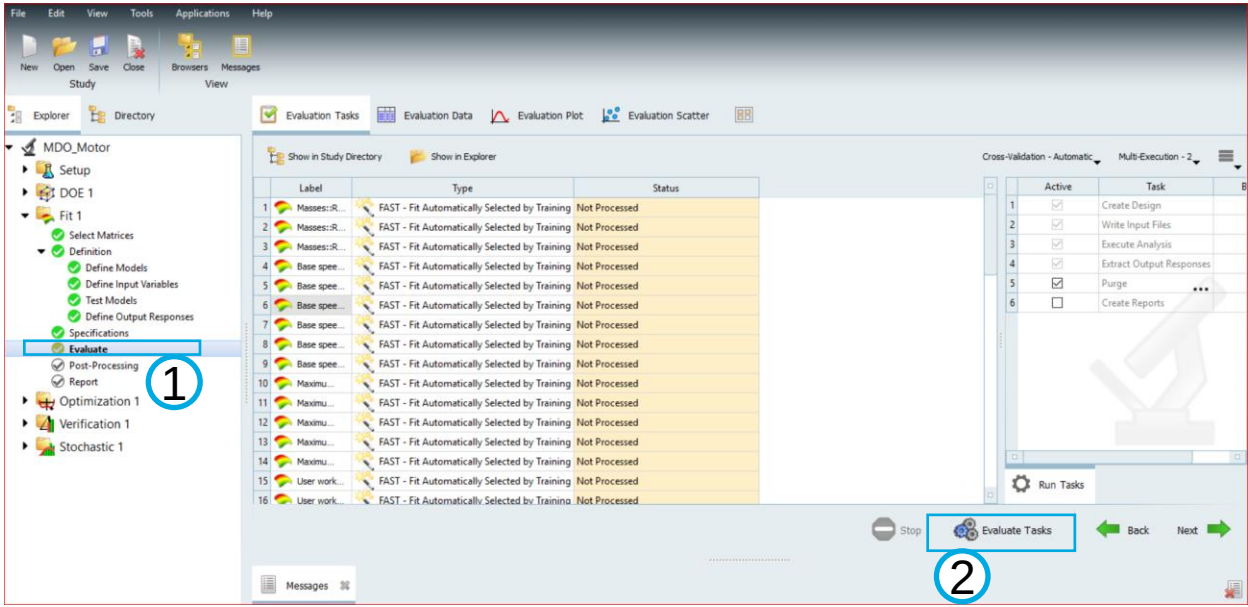
FIT FUNCTION COMPUTATION

- Fit function computation process
  - Evaluate tasks

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



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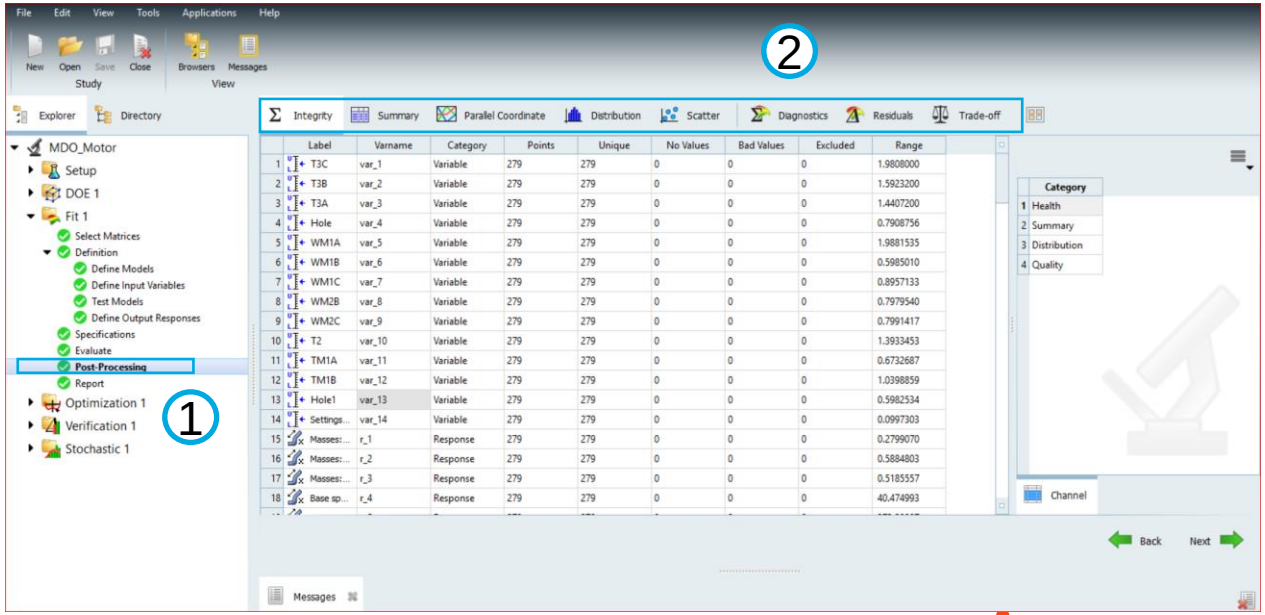
FIT FUNCTION COMPUTATION

- 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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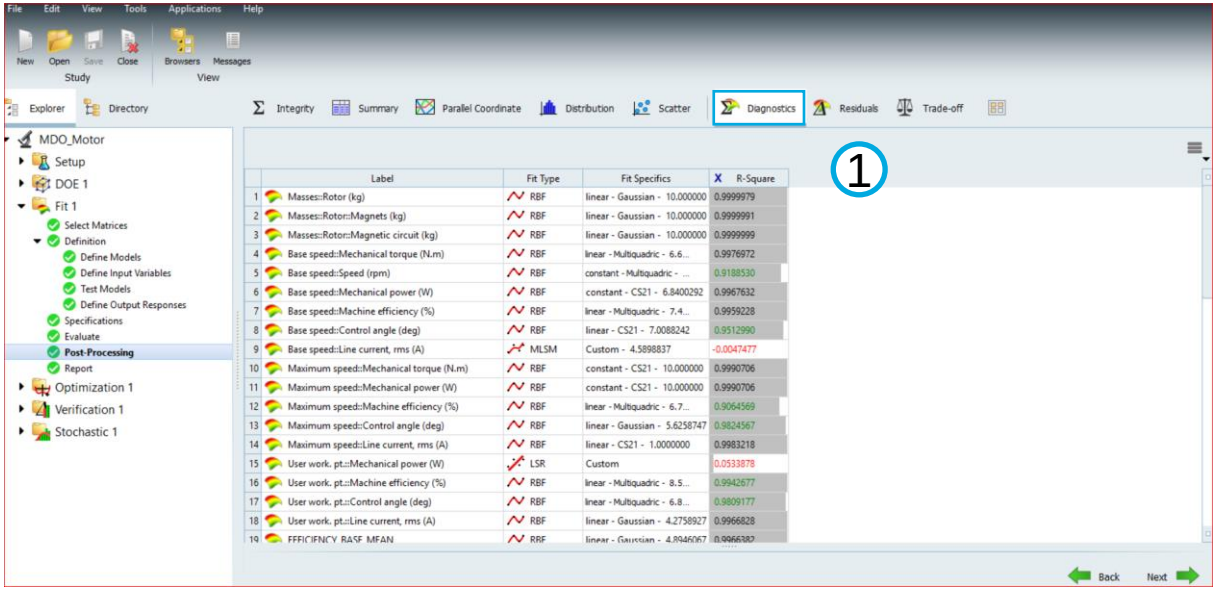
FIT FUNCTION COMPUTATION

- 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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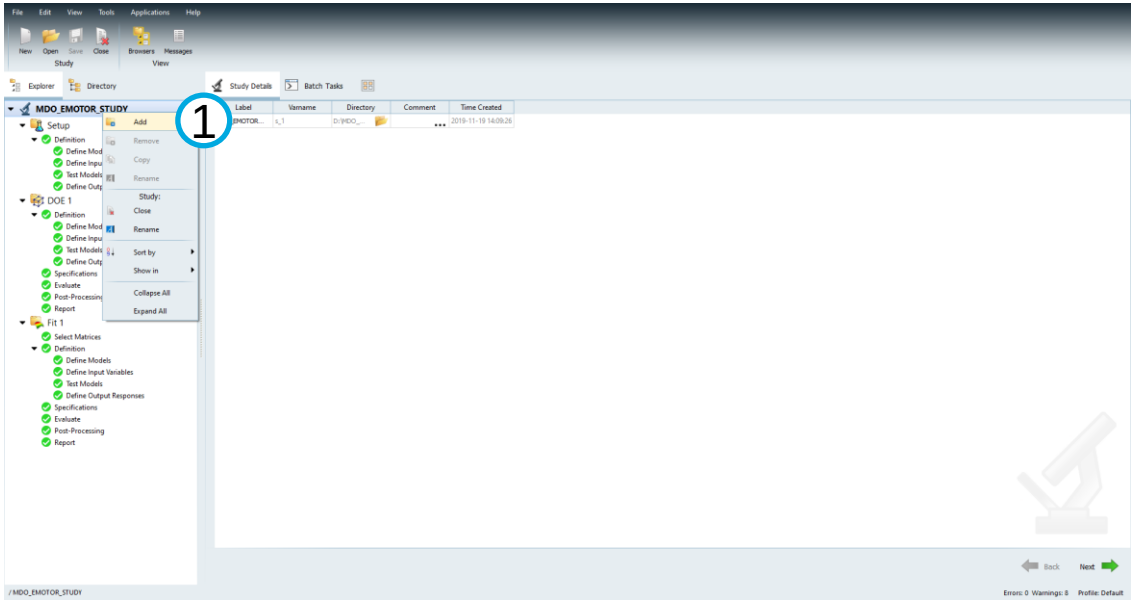
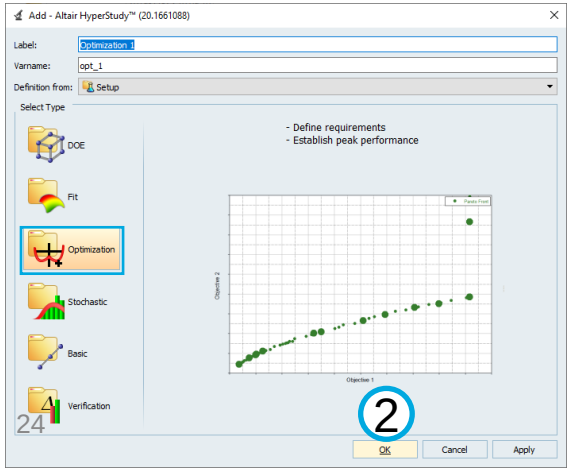
OPTIMIZATION PROCESS

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]

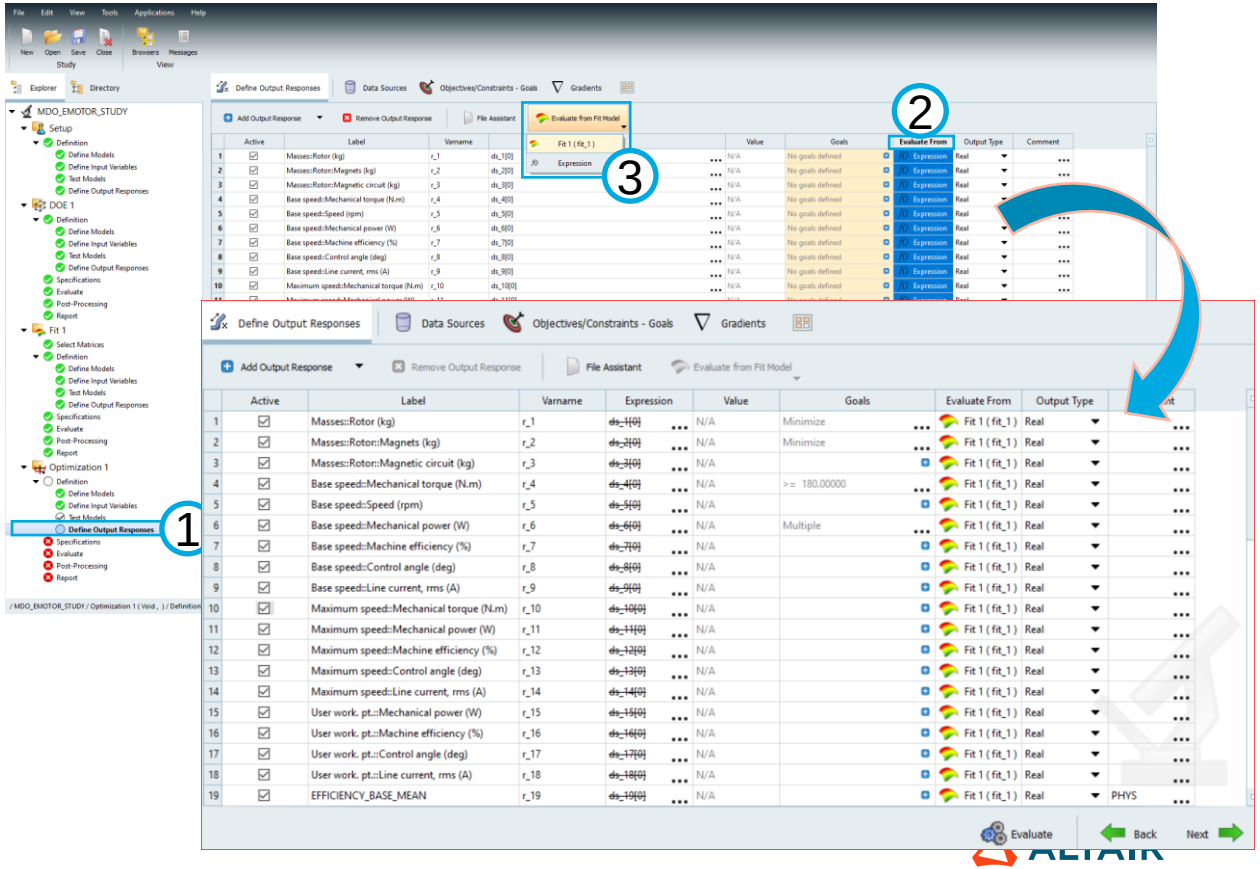




OPTIMIZATION PROCESS

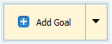
- Optimization initialization
  - Link to fit function results

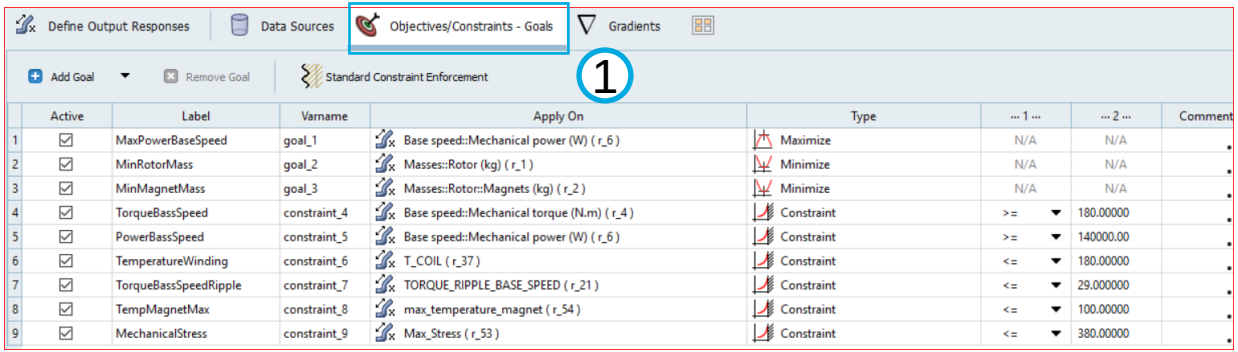
Step	Action
1	Click on [Optimization 1] – [Definition] – [Define output Responses]
2	Click on [Evaluate From] to select all the output responses
3	Click on [Evaluate from Fit Model] – [Fit 1] to link the optimization with the fit functions



OPTIMIZATION PROCESS

- Optimization initialization
  - Define optimization goals and constraints

Step	Action
1	Click on [Objectives/Constraints - goals]
2	Click on the icon  to add - 3 Goals - 6 constraints



	Active	Label	Varname	Apply On	Type	... 1 ...	... 2 ...	Comment
1	☑	MaxPowerBaseSpeed	goal_1	Base speed::Mechanical power (W) (r_6)	Maximize	N/A	N/A	
2	☑	MinRotorMass	goal_2	Masses::Rotor (kg) (r_1)	Minimize	N/A	N/A	
3	☑	MinMagnetMass	goal_3	Masses::Rotor::Magnets (kg) (r_2)	Minimize	N/A	N/A	
4	☑	TorqueBassSpeed	constraint_4	Base speed::Mechanical torque (N.m) (r_4)	Constraint	>=	180.00000	
5	☑	PowerBassSpeed	constraint_5	Base speed::Mechanical power (W) (r_6)	Constraint	>=	140000.00	
6	☑	TemperatureWinding	constraint_6	T_COIL (r_37)	Constraint	<=	180.00000	
7	☑	TorqueBassSpeedRipple	constraint_7	TORQUE_RIPPLE_BASE_SPEED (r_21)	Constraint	<=	29.000000	
8	☑	TempMagnetMax	constraint_8	max_temperature_magnet (r_54)	Constraint	<=	100.00000	
9	☑	MechanicalStress	constraint_9	Max_Stress (r_53)	Constraint	<=	380.00000	

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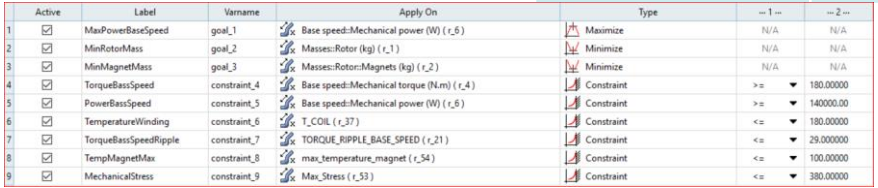
OPTIMIZATION PROCESS

- 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		
MinMagnetMass	goal_3	Masses::Rotor::Magnets (kg) (r_2)	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	<=	380



	Active	Label	Varname	Apply On	Type	... 1 ...	... 2 ...
1	☑	MaxPowerBaseSpeed	goal_1	Base speed::Mechanical power (W) (r_6)	Maximize	N/A	N/A
2	☑	MinRotorMass	goal_2	Masses::Rotor (kg) (r_1)	Minimize	N/A	N/A
3	☑	MinMagnetMass	goal_3	Masses::Rotor::Magnets (kg) (r_2)	Minimize	N/A	N/A
4	☑	TorqueBassSpeed	constraint_4	Base speed::Mechanical torque (N.m) (r_4)	Constraint	>=	180.00000
5	☑	PowerBassSpeed	constraint_5	Base speed::Mechanical power (W) (r_6)	Constraint	>=	140000.00
6	☑	TemperatureWinding	constraint_6	T_COIL (r_37)	Constraint	<=	180.00000
7	☑	TorqueBassSpeedRipple	constraint_7	TORQUE_RIPPLE_BASE_SPEED (r_21)	Constraint	<=	29.000000
8	☑	TempMagnetMax	constraint_8	max_temperature_magnet (r_54)	Constraint	<=	100.00000
9	☑	MechanicalStress	constraint_9	Max_Stress (r_53)	Constraint	<=	380.00000

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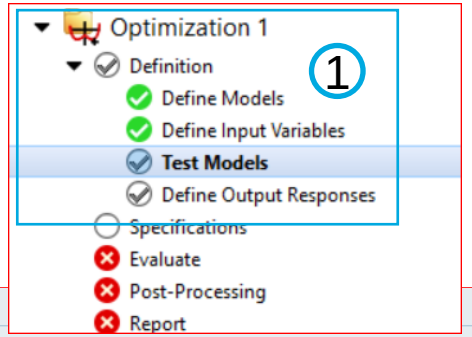
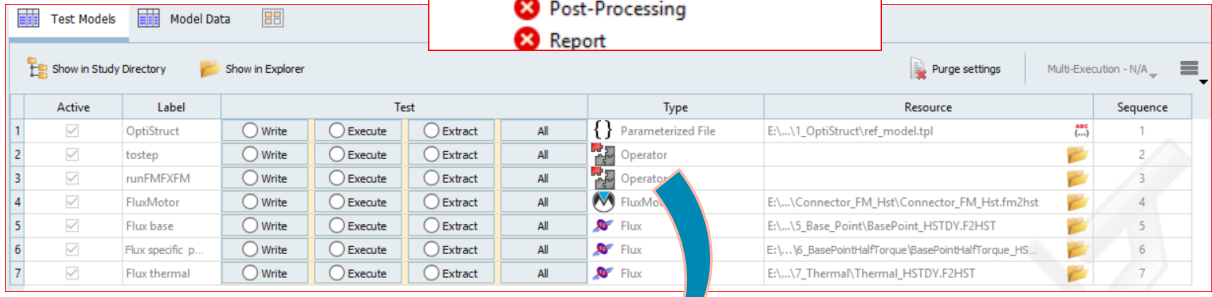
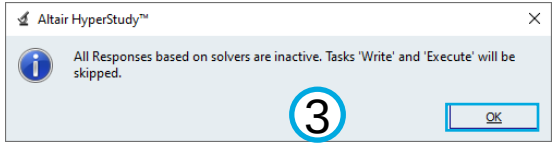
OPTIMIZATION PROCESS

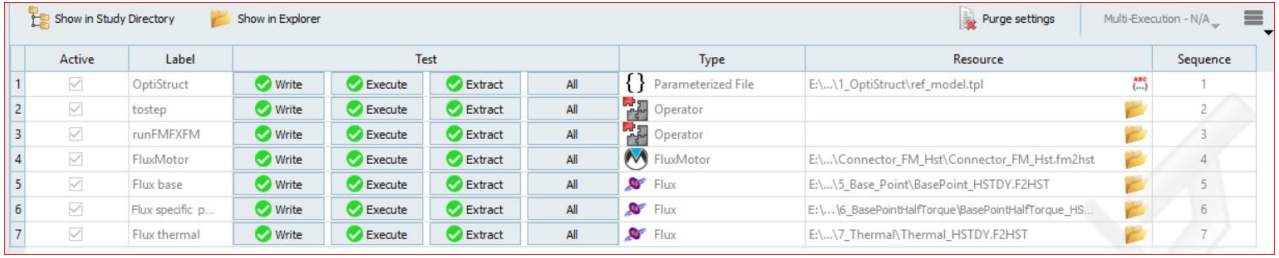
- Optimization initialization
  - Verify model definition

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]









2

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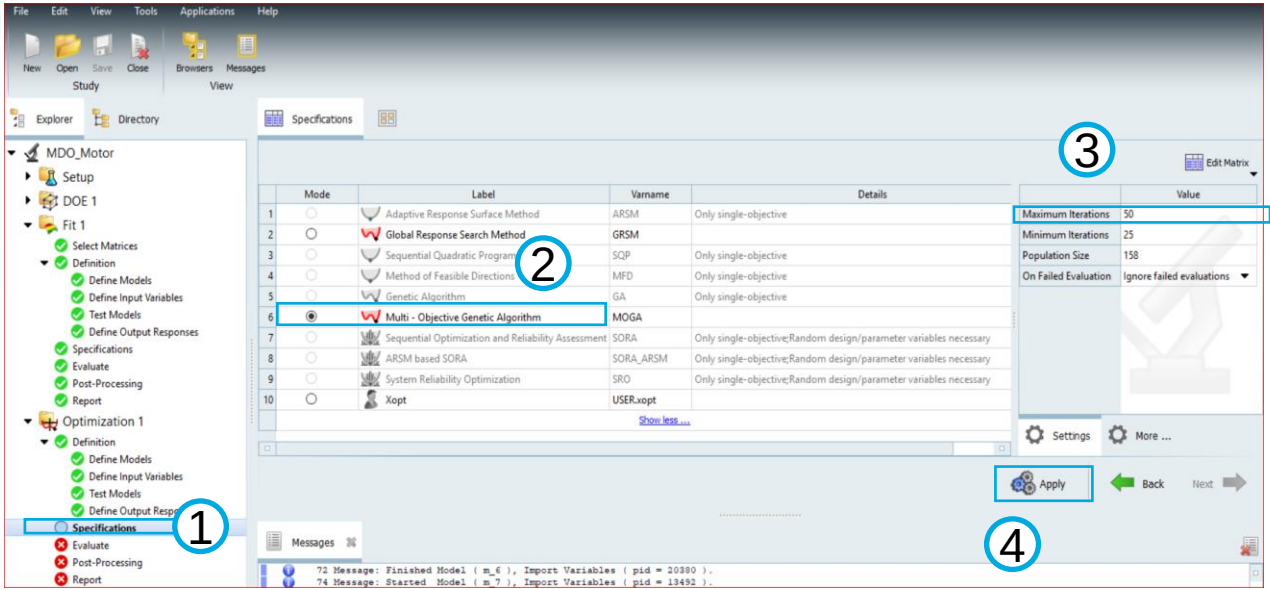
OPTIMIZATION PROCESS

- Optimization initialization
  - Define optimization setting

Step	Action
1	Click on [Specifications]
2	Select “MOGA” algorithm
3	Define the “Maximum Iteration” number 100
4	Click on [Apply]



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

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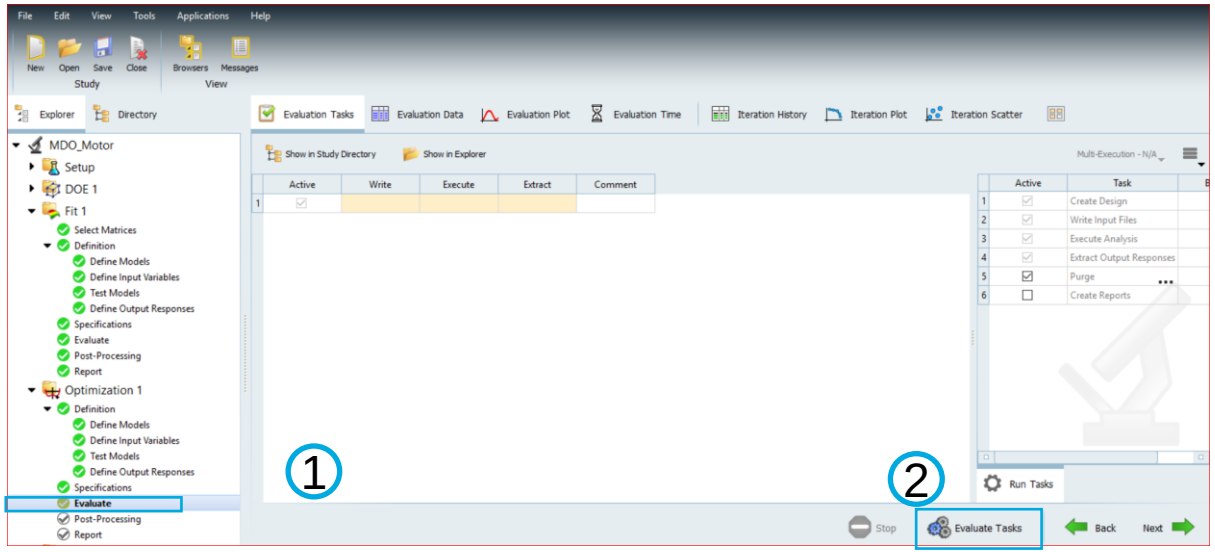
OPTIMIZATION PROCESS

- Optimization evaluation
  - Evaluate tasks for the optimization problem

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



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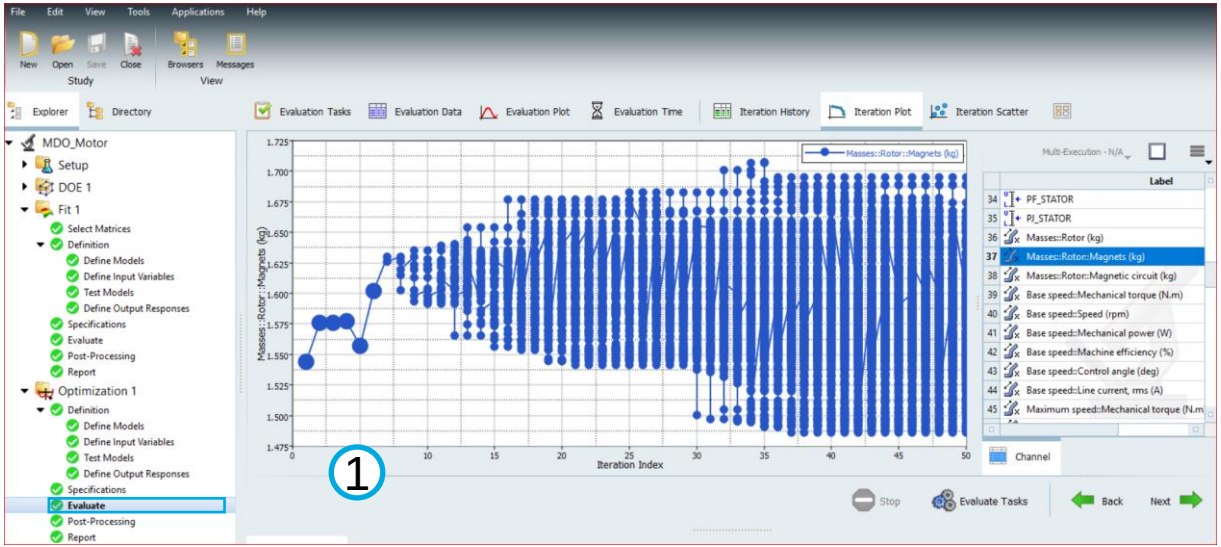
OPTIMIZATION PROCESS

- Optimization evaluation
  - Verify iteration convergence during the optimization process

Step	Action
1	Click on [Iteration Plot]



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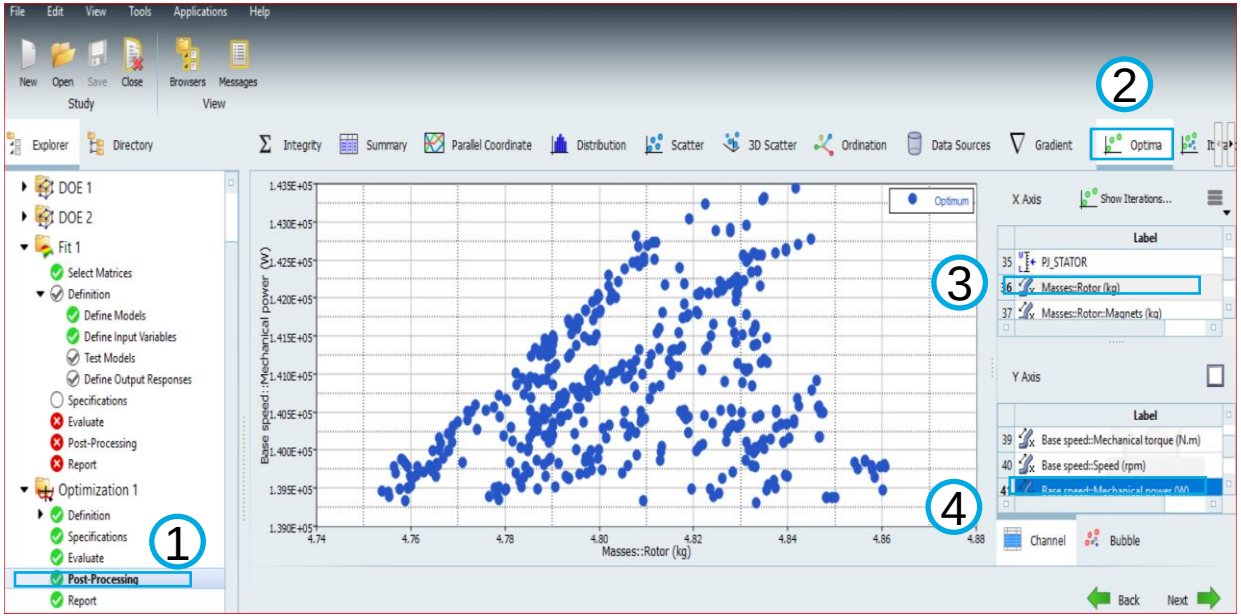
OPTIMIZATION PROCESS

- Optimization post-processing
  - Plot optimal curvev

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”



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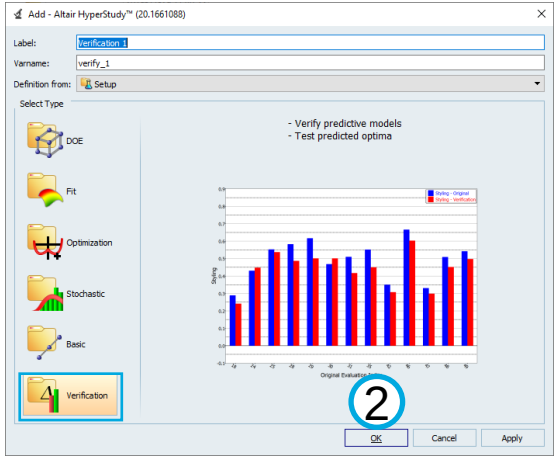
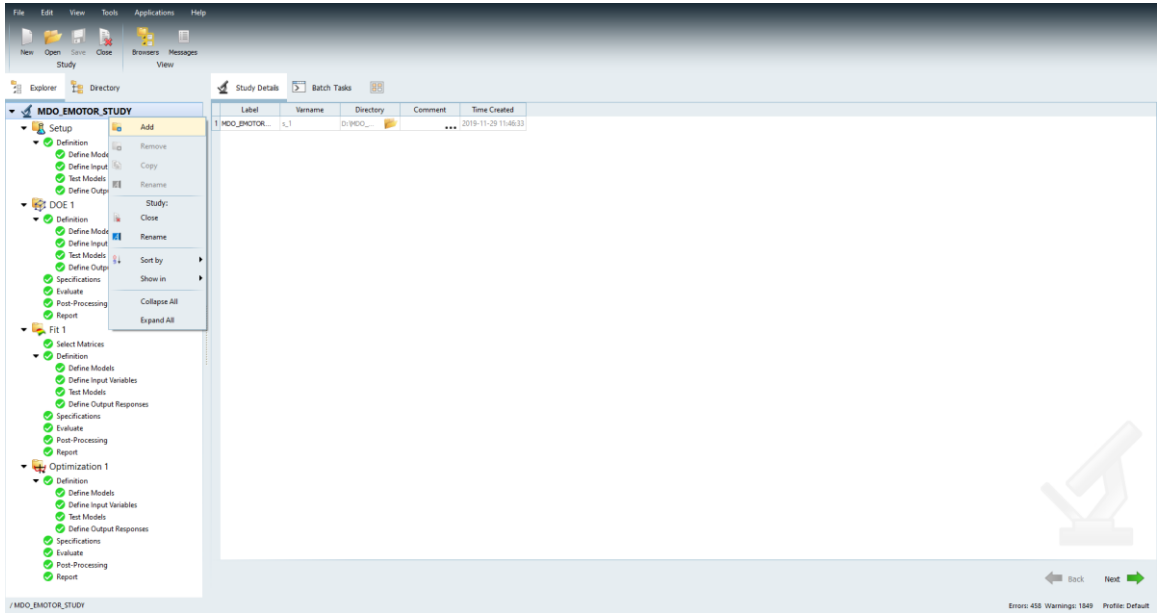
OPTIMIZATION VERIFICATION

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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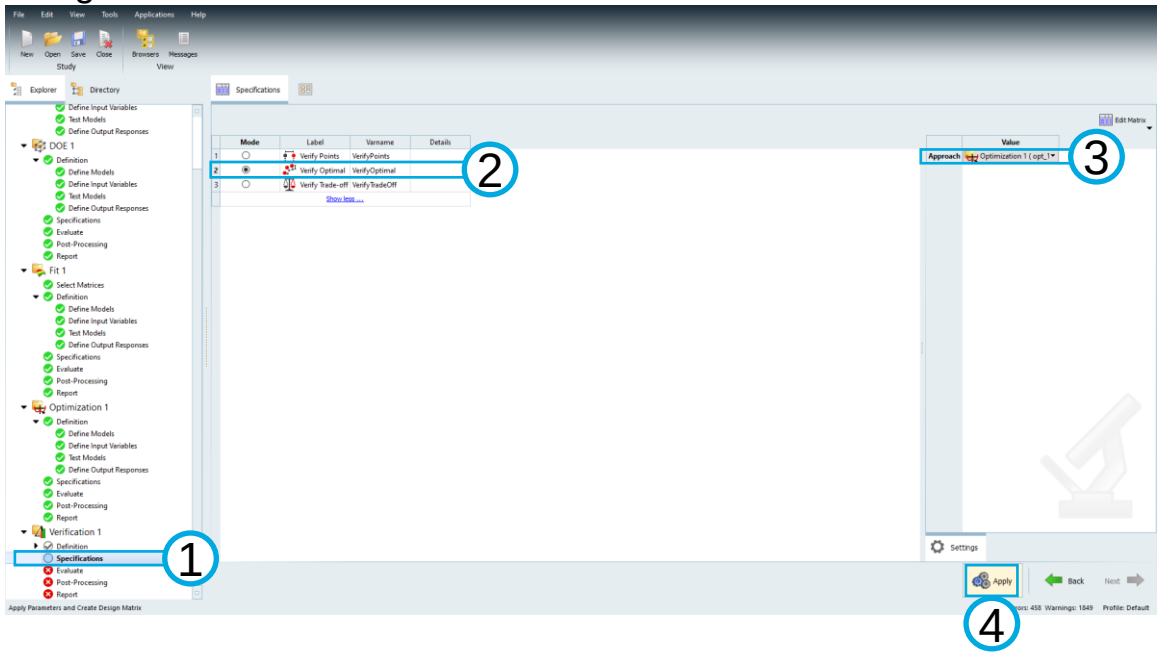
OPTIMIZATION VERIFICATION

- 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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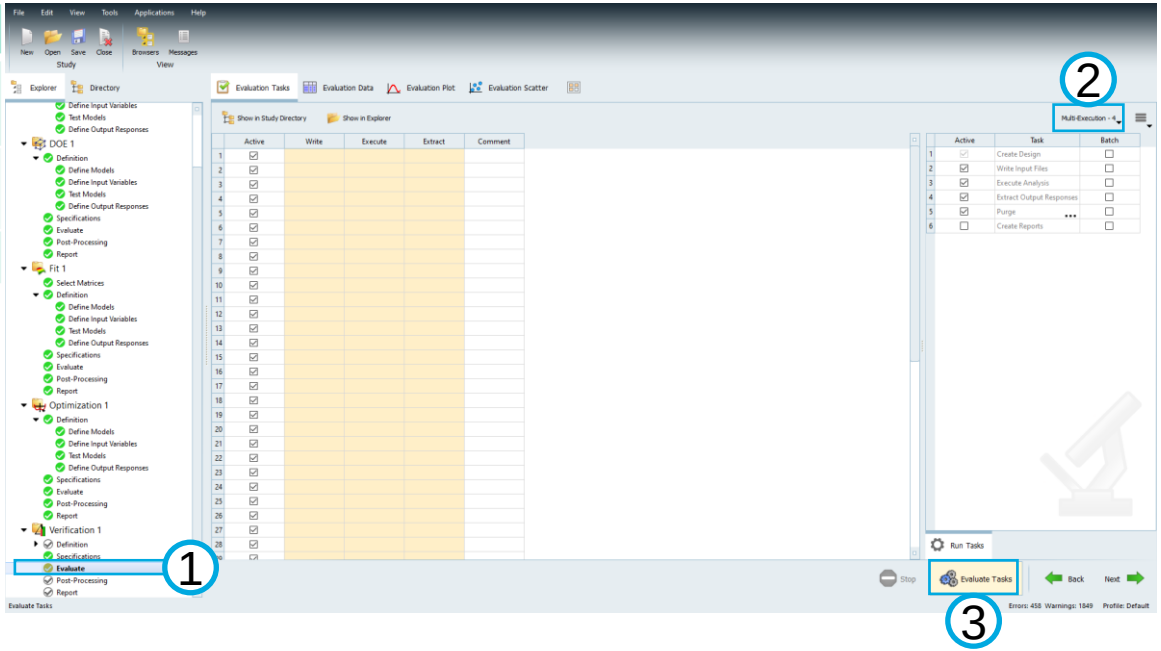
OPTIMIZATION VERIFICATION

- 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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CONCLUSION

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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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