Kewell

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M2000-MS SERIES

E-MOTOR EMULATOR

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KEWELL TECHNOLOGY CO., LTD.

www.Kewelltest.com

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1 Summary

In China and abroad, motor simulation has experienced the development process from real-time model simulation to real-time power simulation, the former being the foundation of the latter. The general system structure of “E-motor Emulator (EME)” consists of three parts: bi-directional power converter, real-time simulator, and closed-loop control system of current.

M2000-MS Series E-Motor Emulator (hereinafter referred to as the M2000-MS Series) is an integrated stationary motor & load simulator, containing dynamic mathematical models for various types of motors (permanent magnet synchronous motors (PMSM), asynchronous motors (ASM), etc.), as well as load models. With the third-generation wide-bandgap power semiconductor device (SICMOSFET) used for the main circuit, and multi-core high-speed processor (FPGA) for the control and model processing units, the M2000-MS Series can accurately simulate motor and load characteristics under various operating conditions and PWM variable frequency drive (VFD) conditions. It also supports online multi-dimensional evaluation of the control performance of electric drive systems based on system operating status monitoring and parameter calculations.

The series is widely used in the R&D and testing of drive motor controllers and general-purpose inverters. It meets the requirements for functional testing, performance testing, durability testing, system calibration, fault injection and functional safety of EV drive motor controllers.

2 Product Composition

On the whole, the product adopts a modular design with separated cabinets. It mainly consists of the electrical power unit (electric cabinet), inductor cabinet (fault injection cabinet), and resolver box, detailed as follows:

- The electrical power unit, employing the AC/DC + DC/AC bi-directional energy circulation technology, achieves the efficient bi-directional conversion and recycling of electrical energy by means of a bi-directional power converter.

- The inductor cabinet is a separate cabinet interlocked with the electrical power unit. It is mainly used for simulation of motor leakage inductance, flux-weakening current, back EMF, and fault injection (three-phase all ON/OFF, L-L short-circuit, open-circuit, shorted to N, etc.).

- The resolver box is setup externally and interlocked with the motor controller, realizing high-accuracy conversion and transmission of motor position and speed signals. It is mainly used to simulate temperature signal, position sensor signal like encoder, resolver and Hall, and faults.

100~300kVA Electric Cabinet

400~500kVA Electric Cabinet

100~300kVA Inductor Cabinet

400~500kVA Inductor Cabinet

100~500kVA Resolver Box

Note: The above pictures are for reference only, and the equipment actually delivered shall prevail.

3 External Conditions

To ensure the successful installation of the equipment in the factory and its stable and reliable operation after installation, and to extend the service life of the equipment, the following requirements for the external conditions need to be met:

3.1 Environmental Requirements

- Ambient temperature: -10℃ ~ +40℃.
- Ambient humidity: 0~90%RH (25°C, non-condensing).
- Altitude: <2000m.

3.2 Site Requirements

- Indoor installation, the floor must be flat and free from standing water, firm and able to support the weight of the equipment.
- The indoor air inlet and outlet must have a specialized dustproof and rainproof design.
- The equipment should be placed so that the front, rear and top have a sufficient distance from the wall to ensure normal ventilation and heat dissipation, and to facilitate maintenance.

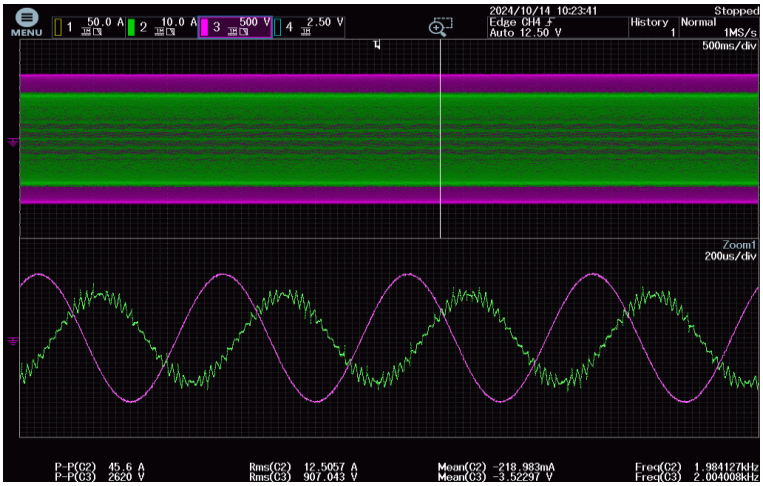
4 Product Features

4.1 New Design

- Modular design, easy operation and maintenance.
- One-button to power up, safe and convenient.
- Ultra-high power density: Up to 176kVA/m³ and above.

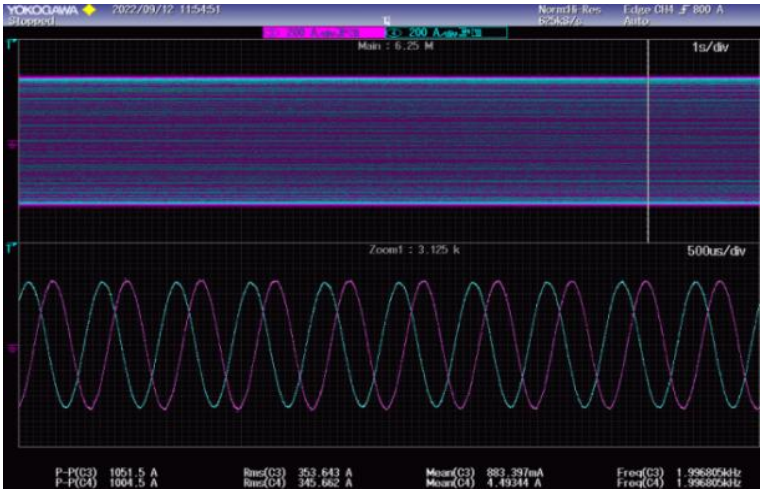
4.2 High Voltage

The M2000-MS Series reaches the max. motor voltage (back EMF) of 900Vrms (L-L), satisfying the requirements of mainstream voltage test platforms.



4.3 Operation at High Speed

The EME can simulate the high-speed operation of motors. Shown below are the waveforms of operation under the condition of 350A/@2000Hz.



Waveform of operation at high speed

4.4 Fast Dynamic Response

Combining powerful hardware platform and optimized software algorithms, the M2000 Series EME obtains fast dynamic response. The current response rate reaches as fast as 2000A/ms.

4.5 High Efficiency

The M2000 Series adopts SiC and a high-frequency design, achieving peak efficiency of up to 94%, which represents a 4% improvement over IGBT-based power frequency solutions. Under long-term test operation, it can effectively reduce power costs, demonstrating greater energy efficiency and environmental friendliness. This is also in line with the carbon neutrality goals.

Efficiency

94% (peak)

Test·duration

8H*30D*12M

Relatively·reduce

34458kg

4.6 No Mechanical Vibration

Without a conventional motor bench, the system configuration is simple and low noise, effectively overcoming such shortcomings of conventional test systems as poor flexibility, complex system structure, high safety risks, and intense mechanical vibration.

4.7 Matching the Vehicle’s Operating Conditions

The system achieves full-load active operation and step pre-setting to cater to the requirements of operating condition testing and to better simulate the vehicle's operating conditions. This enables more reliable and effective verification of drive motor controllers.

5 System Applications

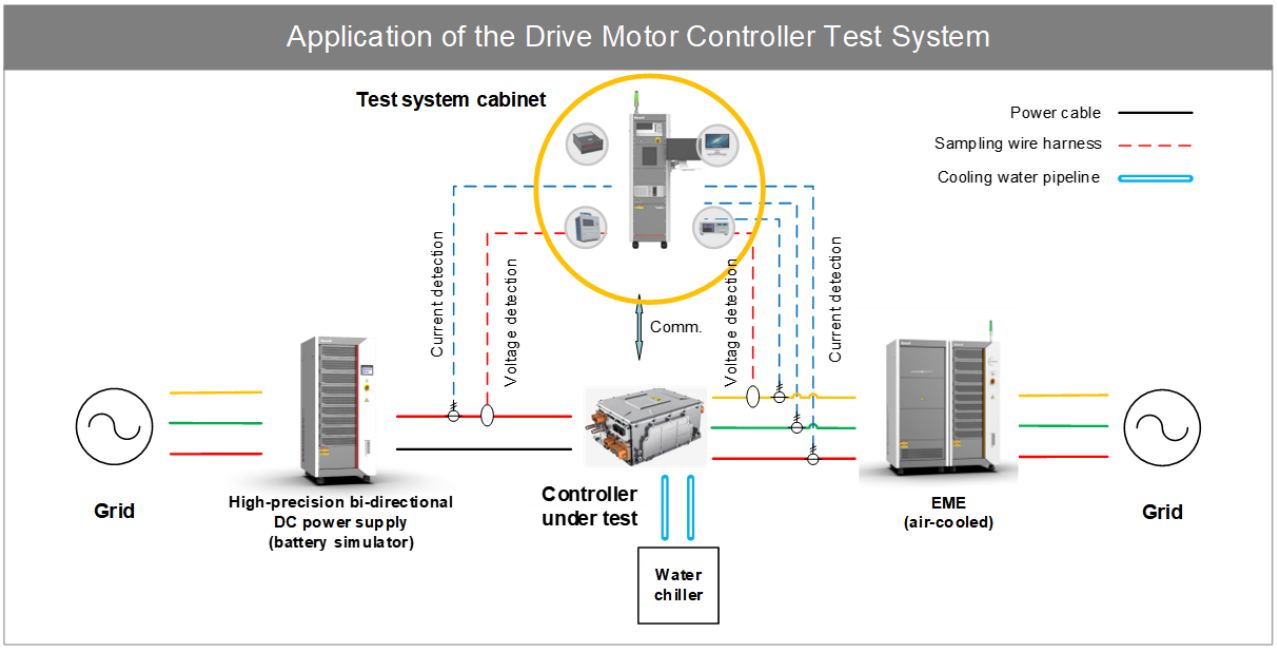
5.1 Application Scenarios

- Motor controller/frequency converter test systems that require EME
- Design verification in the R&D process: function/performance test, fault test, verification of the control loop
- EOL testing: power cycling, durability
- Motor controller power HiL (PHIL) testing
- Micro-grid logic verification
- Third-party inverter testing

5.2 Typical Applications

The EME, based on a precise mathematical model of motor dynamics, precisely simulates both the driving and generating status of the motor. Through the manipulation of relevant digital parameters, various motor body parameters and mechanical load torques can be set or adjusted to accurately mimic the port characteristics of motors with diverse performance profiles. This capability allows it to replace a motor power bench and simulate a wide range of motor load conditions of the controller, thereby fulfilling the requirements for testing drive motor controllers.

The M2000 series is mainly utilized for motor controller / frequency converter testing. The test system, equipped with an E-motor Emulator, overcomes the shortcomings of conventional bench test systems such as poor flexibility, complex system structure, unreliable performance, high safety risks, high component costs, as well as mechanical vibrations and loud noise.

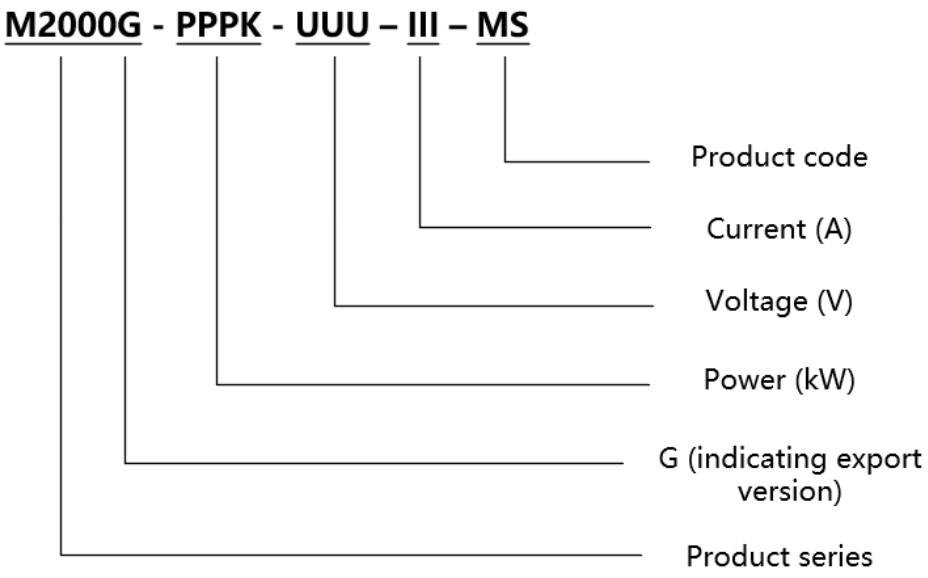


EME-configured motor controller test system diagram

Note: We only provide the software for the M2000-MS EME, not the software for the test system cabinet (it needs to be integrated externally).

6 Product Specifications

6.1 Model Description



6.2 Product Portfolio

Product Model	Power (kVA)	Motor Voltage (Vrms) (L-L)	Rated Current (Arms)	Dimensions (W*D*H) [mm]
M2000G-100K-900-167-MS	100	900	167	1700*1000*2000
M2000G-200K-900-334-MS	200	900	334	1700*1000*2000
M2000G-300K-900-500-MS	300	900	500	1700*1000*2000
M2000G-400K-900-668-MS	400	900	668	3400*1000*2000
M2000G-500K-900-835-MS	500	900	835	3400*1000*2000

6.3 Technical Parameters

Power Supply Parameters	
Grid Phase	3φ3W + PE
Grid Voltage	400V±10%
Grid Frequency	50Hz±5Hz

Power Factor	≥0.99
iTHD	≤3% @full load

EME Parameters	
Phases of Simulated Motor	3
Motor Type	PMSM/ASM
Back EMF	900Vrms (L-L) @load/ 850Vrms (L-L) @source
Rated Speed	120000rpm/pole pair
Current Frequency	0Hz ~ 2kHz (considering motor characteristics, rated current falls as current frequency increases) *The relationship between current frequency and rated current: 1kHz@100% rated current, 1.5kHz@80% rated current, 2kHz@70% rated current
Model Iteration Rate	2μs
Control Mode	Speed control, torque control
Motor Steering	Clockwise/Counter-clockwise
Motor Torque	Positive/Negative
Stator Resistance	0Ω~5Ω
Motor Leakage Inductance	50uH~2650uH
Number of Pole Pairs	1~20
Temperature Sensor	4 signals/channel, NTC or PTC
Position Sensor	Resolver /Encoder/ Hall
Resolver Excitation	3kHz ~ 20kHz
Fault Simulation	Short-circuit/disconnection/locked-rotor/sensor fault/communication fault, etc.
Equivalent Switching Frequency Simulated	≥200kHz
Max. Current Response Rate	≥1500A/ms
Communication Interface	CAN/LAN/485

Environmental Condition and Safety	
Cooling Mode	Forced air cooling
Ambient Temperature	-10℃~40℃
Relative Humidity	0~90％RH (25℃, non-condensing)
Altitude	≤2000m

7 Product Software Description

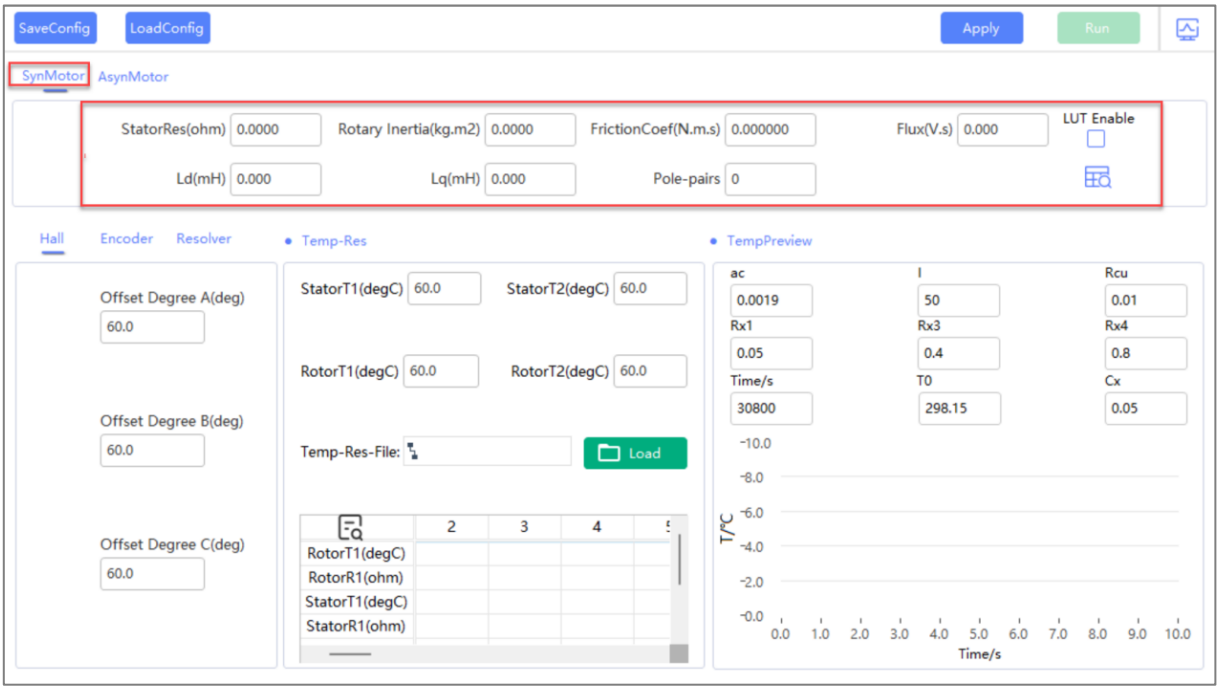
7.1 Main Function

The EME incorporates comprehensive dynamic mathematical models of both PMSM and AC asynchronous motors, along with a wide array of load models. In an intuitive visual interface, the parameters of the motor itself and the mechanical load torque can be effortlessly set or adjusted, facilitating precise and convenient simulation of the motor and load characteristics. Additionally, the EME has the capability to simulate motor temperature and position sensors, while flexibly simulating a variety of faults, including locked rotor conditions, line-to-line (L-L) faults, and sensor faults.

7.2 Motor Emulation

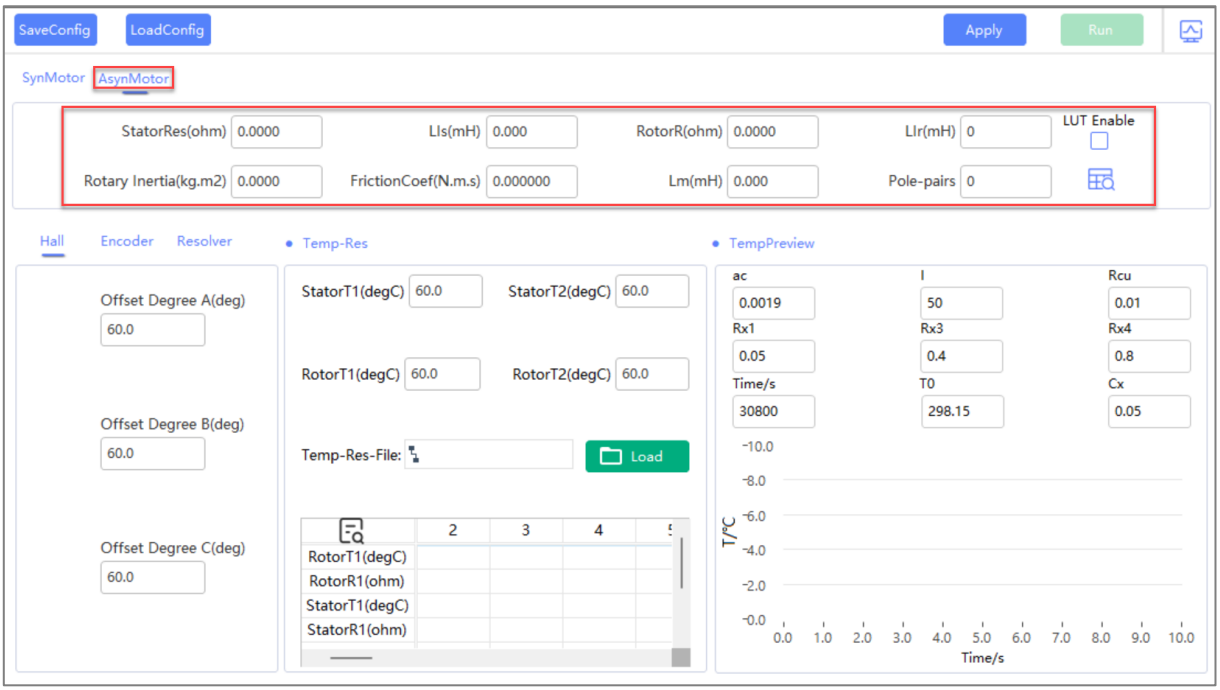
7.2.1 Type of Simulated Motors

A PMSM is defined by the following parameters:



PMSM parameter setting interface

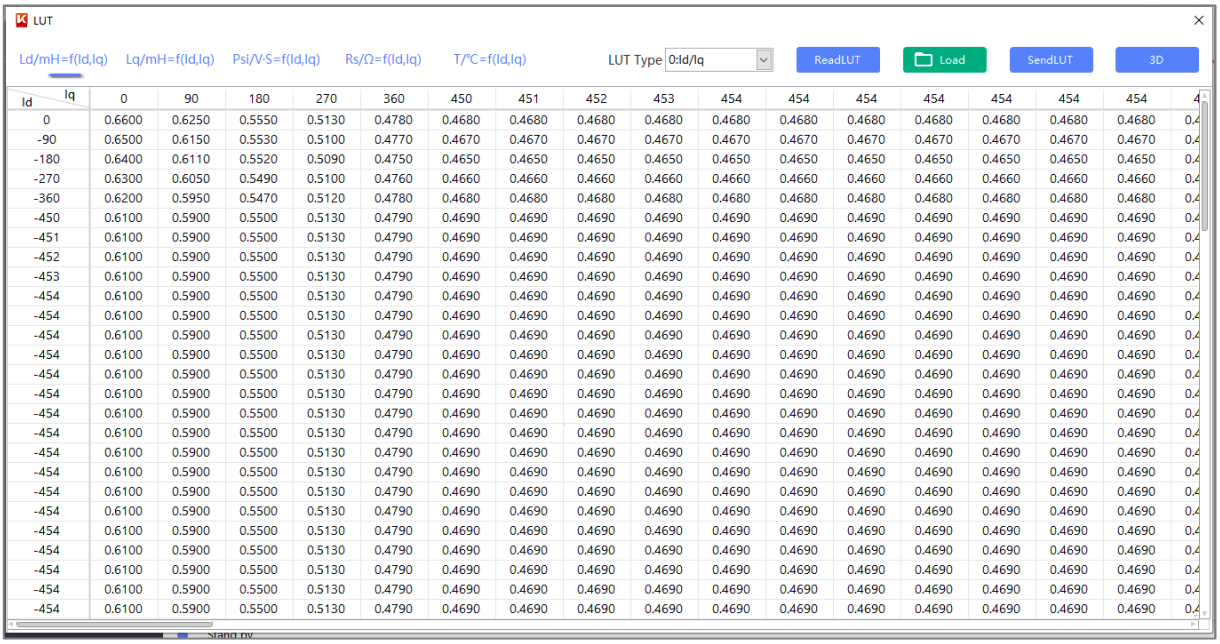
An AC asynchronous motor is defined by the following parameters:



Parameter setting interface of AC asynchronous motor

7.2.2 Nonlinear Simulation (LUT)

The EME supports nonlinear simulation of motors, featuring look-up table function for magnetic flux, leakage inductance and other parameters based on Id and Iq, enabling nonlinear characterization of magnetic flux and leakage inductance during motor simulation.



Id \ Iq	0	90	180	270	360	450	451	452	453	454	454	454	454	454	454	454	454
0	0.6600	0.6250	0.5550	0.5130	0.4780	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4
-90	0.6500	0.6150	0.5530	0.5100	0.4770	0.4670	0.4670	0.4670	0.4670	0.4670	0.4670	0.4670	0.4670	0.4670	0.4670	0.4670	0.4
-180	0.6400	0.6110	0.5520	0.5090	0.4750	0.4650	0.4650	0.4650	0.4650	0.4650	0.4650	0.4650	0.4650	0.4650	0.4650	0.4650	0.4
-270	0.6300	0.6050	0.5490	0.5100	0.4760	0.4660	0.4660	0.4660	0.4660	0.4660	0.4660	0.4660	0.4660	0.4660	0.4660	0.4660	0.4
-360	0.6200	0.5950	0.5470	0.5120	0.4780	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4680	0.4
-450	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-451	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-452	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-453	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4
-454	0.6100	0.5900	0.5500	0.5130	0.4790	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4690	0.4

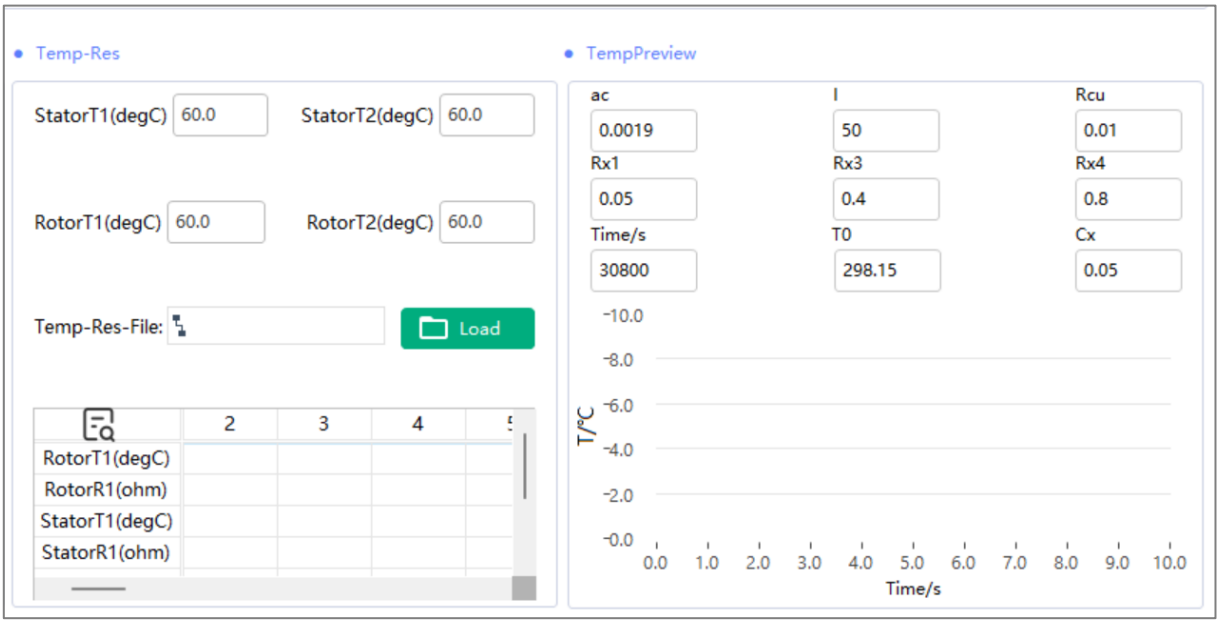
Nonlinear simulation interface

7.2.3 Sensor Simulation

- **Temperature sensor**

The EME can simulate the temperatures of both the motor rotor and stator. It supports simulation of NTC and PTC types with a resistance range of 0~100KΩ. The temperature is fed back in the form of signals, and the EME has 4 temperature signal outputs. Users can create their own temperature/resistance tables, where the “rotor/stator temperature (℃)” is the input, and the rotor/stator temperature expressed in resistance (Ω) is the output. The table provides a total of 30 sets of data setting range.

The user sets the rotor and stator temperatures via the software interface, and the system correspondingly outputs the resistance values representing the temperatures based on the custom temperature table and the set temperature values.

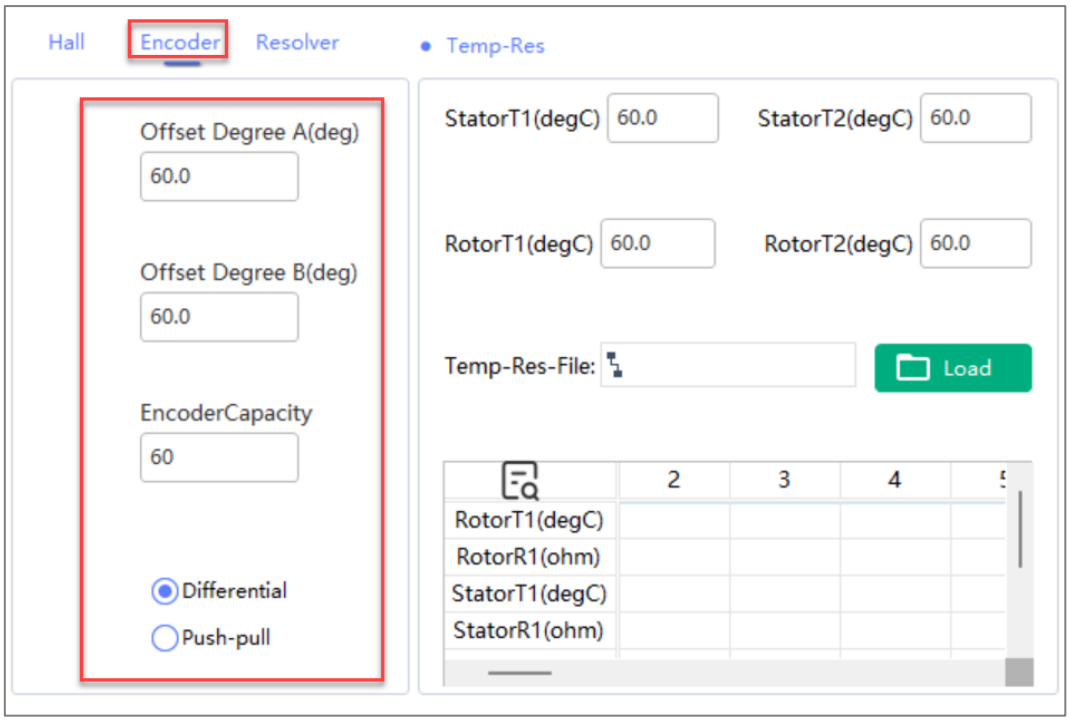


Temperature sensor setting interface

- **Encoder sensor**

The EME can simulate a photoelectric encoder position sensor and output three digital signals: A, B, and Z with a voltage amplitude of 5V. It also provides users with two output modes to select from: OC/ Push-Pull. Users can connect to an external DC 12~24V power supply to meet the requirements of encoder sensors with different voltage levels. Additionally, users can set the offset angle of signal A and B to simulate the phase shift of the sensor signals.

Users can set the encoder output mode, signal offset angle, etc. according to actual requirements.

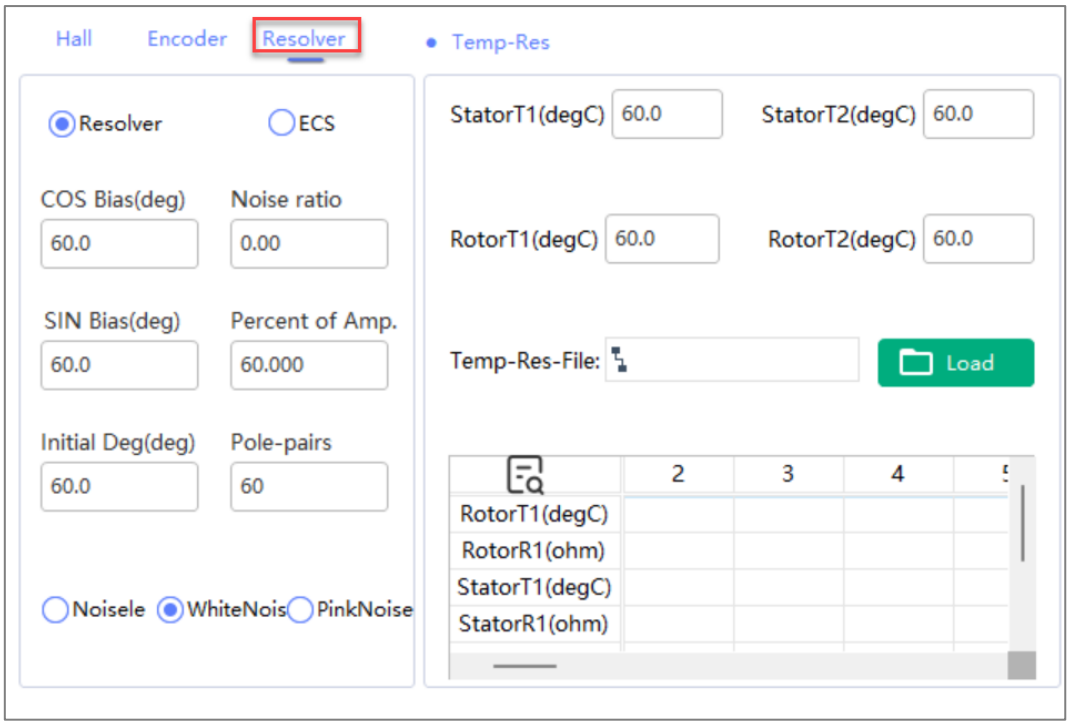


Encoder setting interface

- **Resolver sensor**

The EME can simulate a resolver. The number of pole pairs can be set, and the proportional factor of the output amplitude of the sine and cosine signals can be adjusted to prevent voltage amplitude reduction due to issues such as line impedance. Additionally, users can set the offset angles of the SIN, COS, and rotor signals to simulate sensor signal phase shifts and initial angle offsets. Users can also set the electrical angle of the magnetic pole and the number of resolver pole pairs. Furthermore, up to 6 disturbance levels can be injected within each excitation cycle to simulate resolver disturbances.

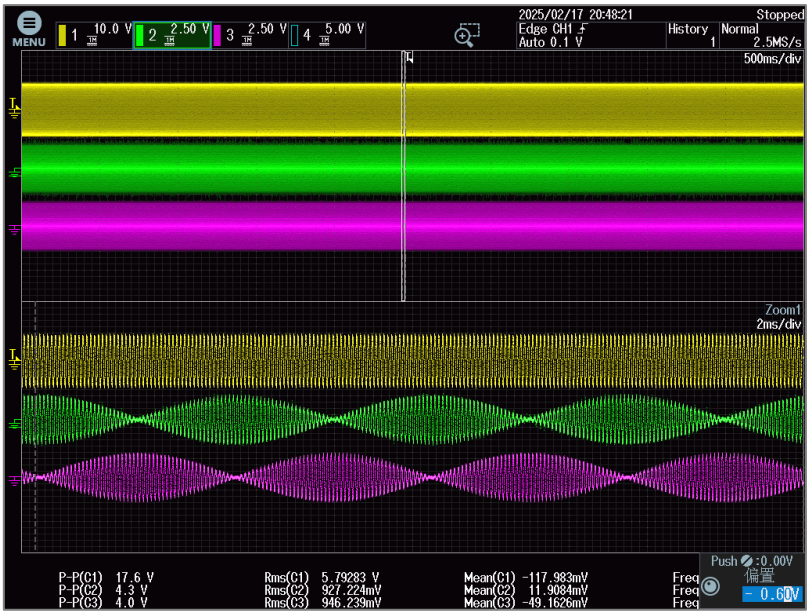
The resolver sensor setting interface is as shown below.



Resolver sensor setting interface

*Note: The eddy current model is optional, users may decide whether to select this function based on actual needs.

The normal resolver signals (excitation, sine, and cosine) are shown in the figure below:



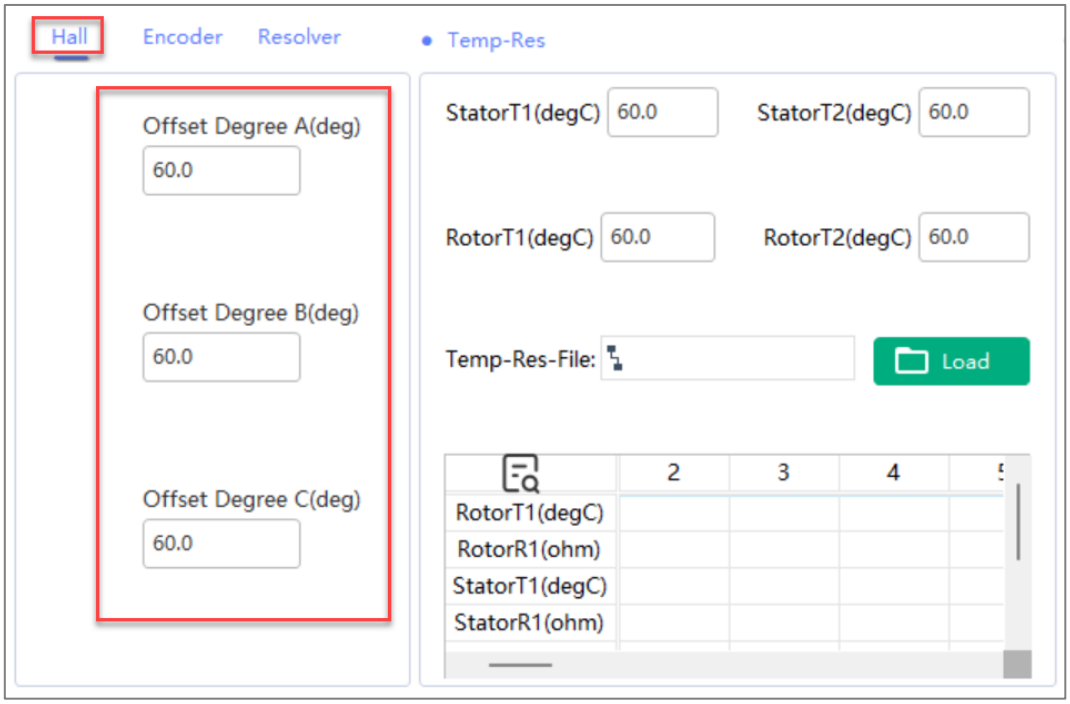
Resolver (excitation, sine, and cosine) signals

- **Hall sensor**

The EME can simulate a Hall position sensor and output four digital signals: A, B, C, and Z with a

voltage amplitude of 5V. Users can also set the offset angles of the signal A, B, and C to simulate the phase shift of Hall sensor signals.

The Hall sensor setting interface is as shown below, where users can set the offset angles of the signal A, B, and C according to actual requirements.



Hall sensor setting interface

7.2.4 Load Simulation

The EME can operate in both speed and torque load modes, and it provides settings for both conditions.

- **Speed mode**

In the speed mode, the EME controls the speed, while the controller under test controls the torque. The speed mode setting interface is shown below, where “Set Speed” (rpm), “Speed Slope” (rpm/s), “Speed Increment” and other parameters can be set in the visualized interface.

Note: “Increment” supports the speed to change by a set step size. For example, if you set it to 100 and click the “+” or “-” button, it will change the operating speed in real-time by 100 rpm from the current speed.

Speed mode setting interface

- **Torque mode**

In torque mode, the EME controls the torque, while the controller under test controls the speed. The EME provides 5 different load types.

① (Gravitational) Potential energy load

The load torque has a fixed direction that does not change with the direction of rotation. Regardless of whether the weight is lifted (n is positive) or lowered (n is negative), the direction of the load torque remains unchanged. In the potential energy load mode, key parameters such as “constant torque coefficient”, “torque (N*m)”, “slope (N*m/s)”, and “increment” can be set.

Potential energy load setting interface

② Reactive (friction torque) load

The value of the load torque remains constant, while the direction of the load torque is always opposite to the direction of rotation, meaning that the nature of the torque is always a braking torque. In the reactive load mode, key parameters such as “resistance load coefficient”, “torque (N*m)”, “slope (N*m/s)”, and “increment” can be set.

Reactive load setting interface

③ Constant power load

The load speed is roughly inversely proportional to the torque, and the motor output power remains

basically constant. In the constant power load mode, key parameters such as “constant power”, “slope (N*m/s)”, and “increment” can be set.

Constant power load setting interface

④ Viscous load

The load speed is roughly proportional to the torque, the faster the speed, the larger the torque. In the viscous load mode, key parameters such as “viscosity coefficient”, “slope (N*m/s)”, and “increment” can be set.

Viscous load setting interface

⑤ Fan load

Fan-type loads such as ventilators, water pumps, oil pumps, and propellers, also known as square torque loads, have a torque that is proportional to the square of the rotational speed. In the fan-type load mode, key parameters such as “fan load coefficient”, “slope (N*m/s)”, and “increment” can be set.

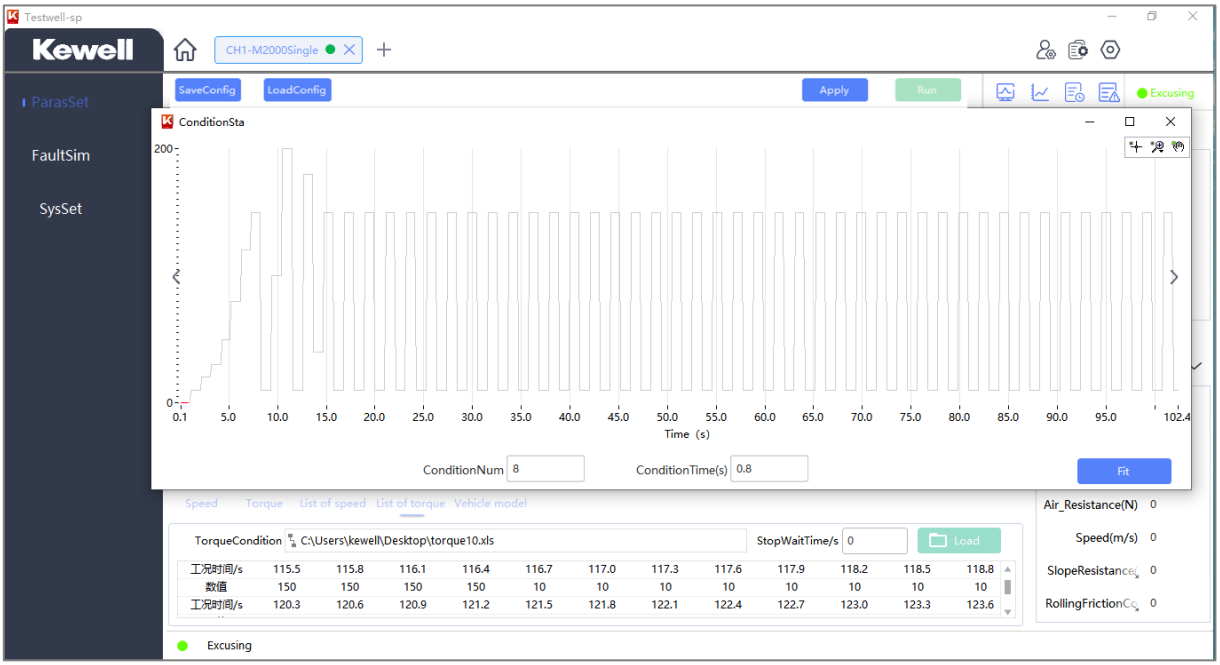
Fan load setting interface

- **Speed operating condition**

It supports importing files in which speed varies over time, and the EME runs automatically according to the set speed condition, while the operating curve of the speed condition can be

viewed.

The operation record is shown in the figure below:



Real-time curve of speed operating condition

- **Torque operating condition**

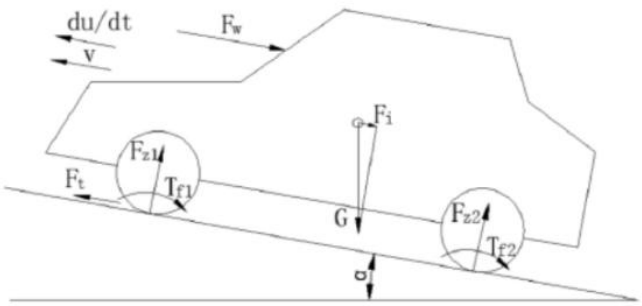
It supports importing files in which torque varies over time, and the EME runs automatically according to the set torque condition, while the operating curve of the speed condition can be viewed.

The operation record is shown in the figure below:

Real-time curve of torque operating condition

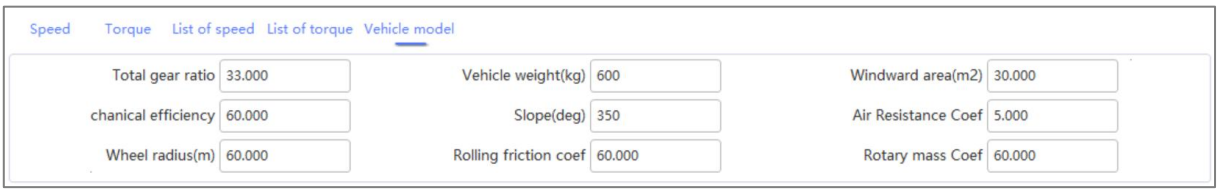
- **Vehicle model**

Through the setting of the total gear ratio, total weight, wheel radius, windward area and other vehicle information as well as the air resistance coefficient, slope and other external environmental factors, the controller inputs the torque and the EME outputs the corresponding speed to simulate of the vehicle's operating condition in the corresponding status.



Vehicle model diagram

The setting interface is shown in the figure below:



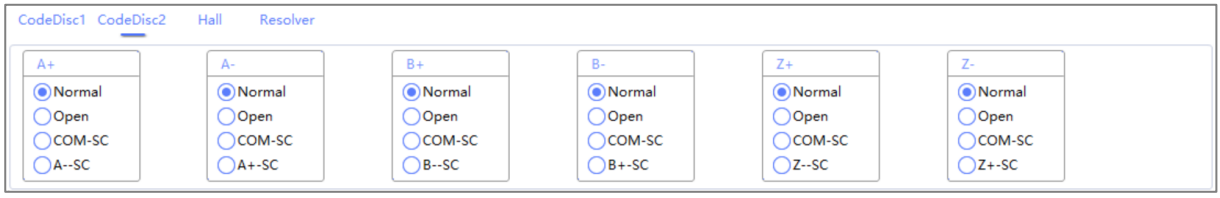
Vehicle model setting interface

7.2.5 Fault Injection

The EME can simulate a variety of faults, covering encoder, resolver, Hall sensor, temperature sensor faults, inter-phase short-circuit/open-circuit, and locked-rotor.

- **Encoder signal fault**

The encoder outputs three digital signals, namely ABZ signals, which we use to simulate the speed, direction, and position of the motor rotor. Additionally, in the following interface, we can set the status (normal, open circuit, short circuit, etc.) of each signal line of the encoder signal to simulate encoder signal fault.

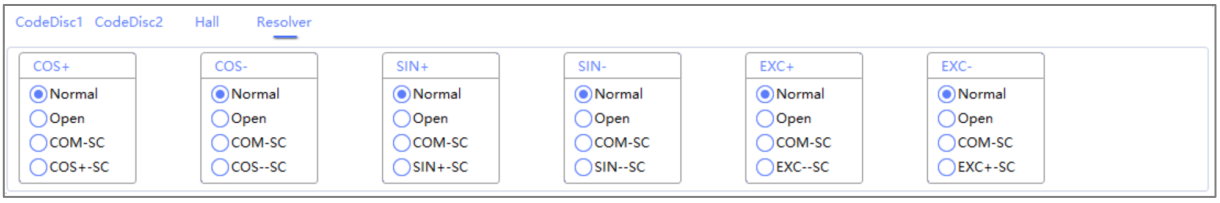


Encoder signal setting interface

- **Resolver signal fault**

The resolver is a position encoder in the motor, and we simulate the position, speed, and direction of the motor rotor by outputting sine/cosine signals. Additionally, we can simulate resolver signal fault in the setting interface below.

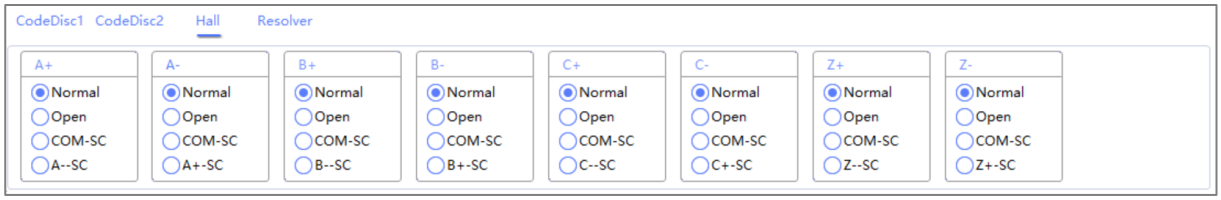
The setting interface is shown in the figure below:



Resolver signal setting interface

- **Hall signal fault**

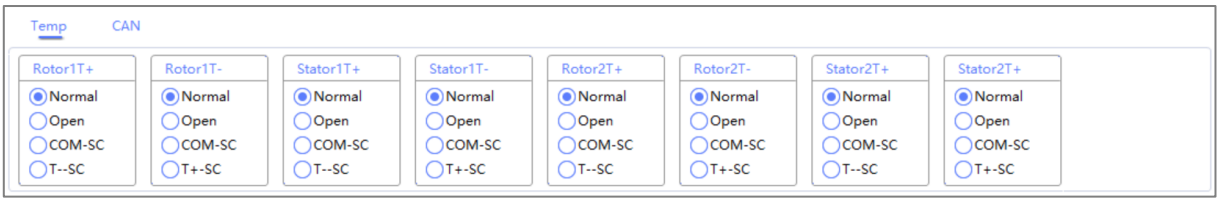
The EME can simulate Hall signal fault by setting the status (normal, open circuit, short circuit, etc.) of each signal line of the Hall signal through the following interface.



Hall signal setting interface

- **Temperature signal fault**

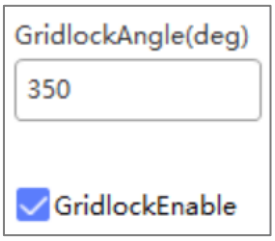
The rotor and stator temperature signal faults are simulated through the interface below.



Temperature signal setting interface

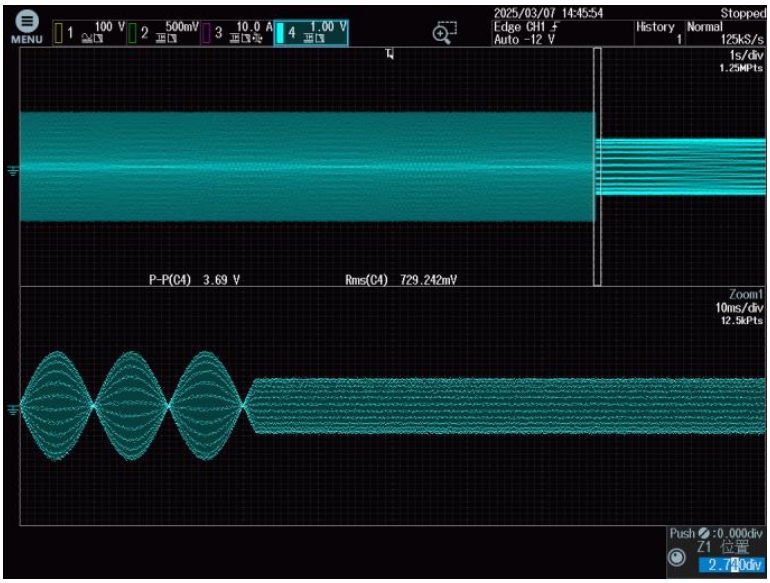
- **Locked-rotor simulation**

Locked rotor is a condition where the motor still outputs torque even when the speed is 0 rpm, mainly caused by excessive motor load, mechanical failure of the driving equipment, or bearing damage. The EME, with a dynamic speed up to $10*10^6$ rpm/ms, can effectively simulate locked-rotor situation. Additionally, it can identify the locked-rotor position.



Locked-rotor simulation setting interface

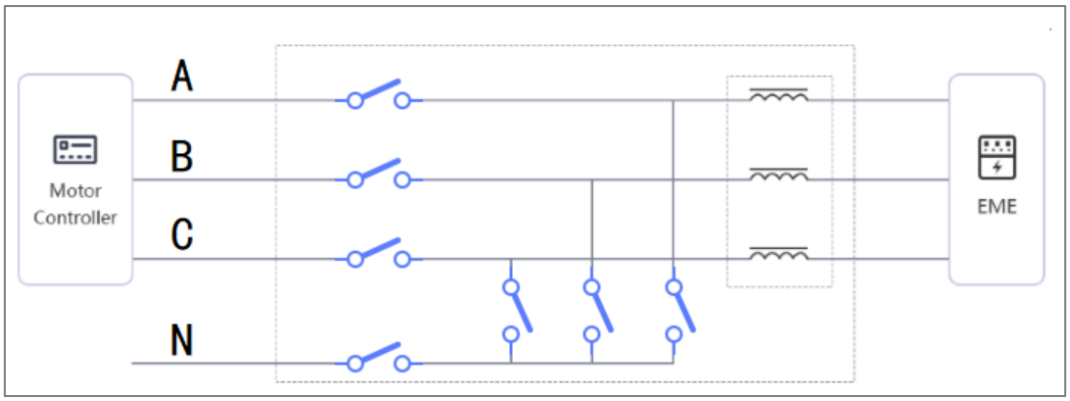
The three-phase current during locked-rotor operation is shown in the figure below:



Measured waveform of locked-rotor simulation

- **L-L fault simulation**

The EME's fault simulation cabinet is equipped with short-circuit and open-circuit switch circuits. By selecting the status of each contactor, different output modes can be enabled, such as three-phase ON, three-phase OFF, phase-to-phase short circuit, single-phase or multi-phase open circuit, and phase-to-N short circuit. This can be used for normal output and simulation of severe motor faults, such as motor out-phase and phase-to-phase short circuit.



L-L fault simulation setting interface

- **CAN signal fault**

The EME has two CAN signals, and the status (normal, open circuit, shorted to COM, shorted to the other CAN line, etc.) of the CANH and CANL signal lines for CAN1 and CAN2 can be set separately through the following interface, so as to simulate CAN signal fault.

CAN signal fault simulation interface

- **Other faults**

① Impedance change simulation

When there is a turn-to-turn short circuit of stator winding, impedance changes will occur. The EME opens to users the setting of stator resistance parameters to simulate impedance changes.

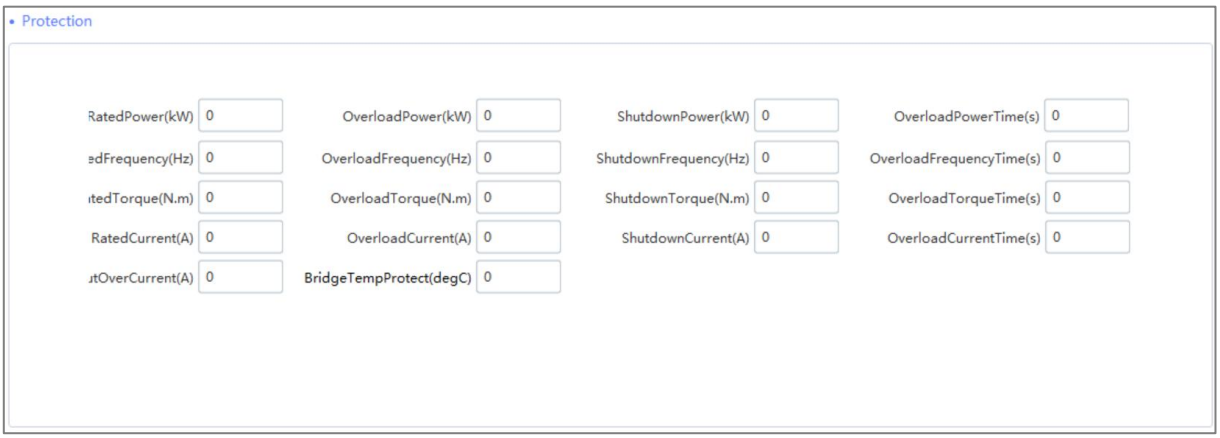
② Demagnetization simulation

Demagnetization refers to the phenomenon of magnetic properties fading in the permanent magnet in the motor. There is no demagnetization in a three-phase AC asynchronous motor. For PMSM, users can simulate its demagnetization by setting the magnetic flux.

7.2.6 Status and Protection

- **Protection setting**

The M2000-MS Series EME has safety protection mechanisms for overvoltage, overcurrent, overpower, over-temperature and other situations. It monitors the equipment operating status and takes protective actions when the safety thresholds are exceeded, to protect the equipment from damage caused by excessive voltage, current, power or temperature.



Protection setting interface

- **Fault query**

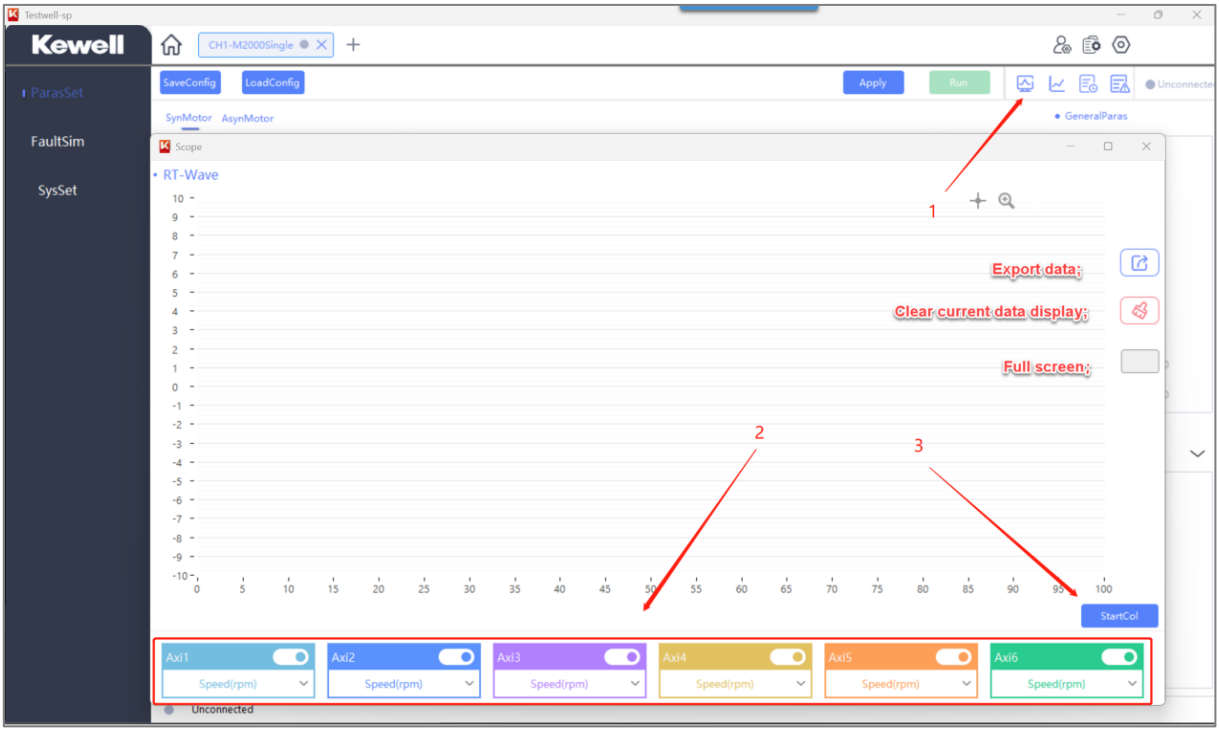
It supports recording of fault at the moment and query of fault history. Users can view in real time the current faults of the equipment, facilitating fault analysis and processing. After the cause of the fault has been clearly identified, users can easily reset fault status. For fault history, you can query fault information within a certain time frame by setting the start and end time of query.

- **Status display**

It allows real-time viewing of the current operating status parameters of the equipment, mainly including motor speed, electromagnetic torque, electromagnetic power, current (Id, Iq), busbar voltage, and temperature.

7.2.7 Oscilloscope

After the equipment starts normal operation, click 'oscilloscope' and select the parameters to display (up to 6 parameters at the same time), click 'apply' and 'StartCol, and the waveform will be displayed in real time. In the display area, use the left mouse button to drag the waveform in different directions, or use the mouse wheel to zoom in and out. The interface is as shown below:



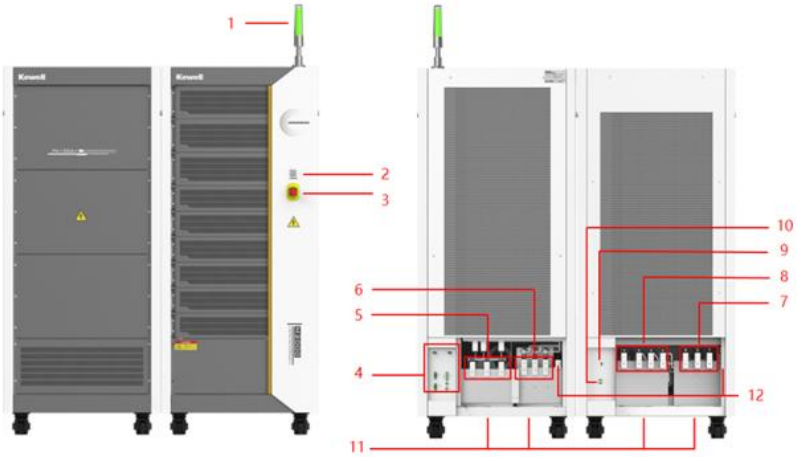
Real-time curve display interface

Note: The software interfaces above are for reference only, and the actual equipment delivered shall prevail.

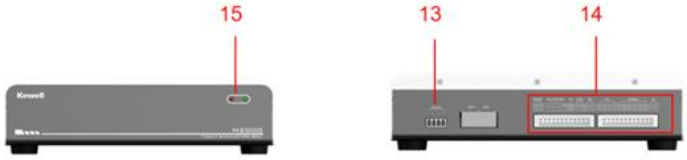
8 Interfaces

The equipment interfaces are introduced below:

1) The 100~300kVA models:



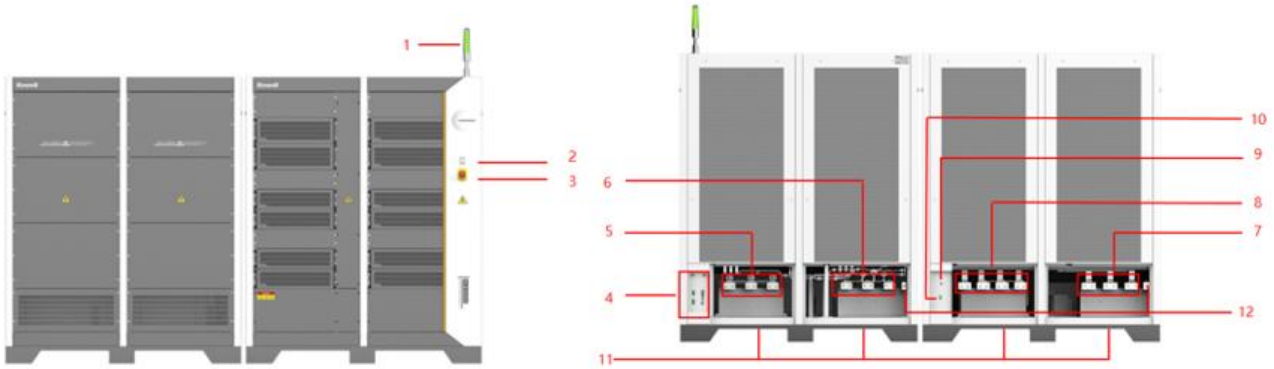
Front View Back View



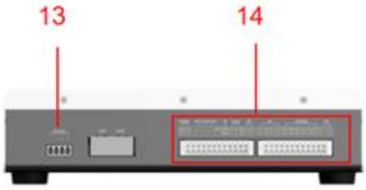
Resolver Box Front View Resolver Box Back View

No.	Name
1	Three-color light
2	Electrical push-button switch
3	Emergency stop button
4	Electric cabinet comm. Interface
5	Electric cabinet output busbar
6	Electric cabinet AC input busbar
7	Fault injection cabinet input busbar
8	Fault injection cabinet output busbar
9	Fault injection cabinet comm. Interface
10	Fault injection cabinet power supply interface
11	Wiring slot
12	Grounding busbar
13	Resolver box power supply interface
14	Resolver box comm. interface
15	Resolver box status indicator

2) The 400~500kVA models:



Resolver box front view



Resolver box back view

No.	Name
1	Three-color light
2	Electrical push-button switch
3	Emergency stop button
4	Electric cabinet comm. Interface
5	Electric cabinet output busbar
6	Electric cabinet AC input busbar
7	Fault injection cabinet input busbar
8	Fault injection cabinet output busbar
9	Fault injection cabinet comm. Interface
10	Fault injection cabinet power supply interface
11	Wiring slot
12	Grounding busbar
13	Resolver box power supply interface
14	Resolver box comm. interface
15	Resolver box status indicator

Note:

The 100~300kVA models have casters on the base, while the 400~500kVA models have channel steel base.