Fault-Injection Benchmark for Traction Drive Control System

User Guide

Version 2.0

2017.11.30

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Central South University

Contents

1 Fault injection benchmark for traction drive control system

The latest version of Fault Injection Benchmark for Traction Drive Control System, TDCS-FIB V2.0 is developed by Central South University, based on the research on traction drive control system for a certain type of high-speed trains and a certain number of fault mechanisms, The major objectives are to build a Simulink simulation model of traction drive control system(TDCS); realize the normal running simulation of TDCS; adopt a variety of fault injection methods and develop a fault injection benchmark based on the simulation model for realizing the injection simulation of the typical single fault and compound fault for the some subsystem such as sensor, traction converter, traction motor and traction controller. TDCS-FIB V2.0 provides a platform for verification, and validation for fault injection, fault detection and diagnosis, fault tolerance control and simulation credibility evaluation method.

Compared with the last version, TDCS-FIB V2.0 has five new features:

1) Rebuilt the system simulation model.

By analyzing the mechanism model of the system, rebuilt the simulation model of traction drive control system based on Simulink.

2) Added new fault injection method.

On the basis of the signal conditioning injection method adopted in version 1.0, added the fault injection method based on mixture of signal conditioning and model replacement.

3) Added new fault injection type.

Added 6 compound faults:

a) Mixture of gain fault (constant value amplification) and deviation fault of U-phase current sensor in the three-phase current of motor stator.

b) Simultaneous deviation of U-phase and W-phase current sensor in the three-phase current of motor stator.

c) CIGBT1 和 CIGBT4 simultaneous open circuit on the A bridge of the three-level rectifier.

d) Mixture of motor rotor bar broken and air gap off-center faults.

e) Mixture of rotor bar broken and stator inter-turn short circuit fault.

f) Mixture of CIGBT1 open circuit fault on the A upper bridge of the three-level rectifier and drift fault of U-phase current sensor in the three-phase current of motor stator.

4) Added new location selection function for fault injection.

For different injection fault type, added the location selection function for fault injection:

a) For the 11 faults of sensor, added 3 optional positions for fault injection: U-phase current sensor, V-phase current sensor, W-phase current sensor in the three-phase current of motor stator.

b) For the 5 faults of traction motor, added 2 optional positions for fault injection: three-phase current sensor of motor stator, inverter output terminal.

c) For analog pulse fault in 3 type faults of traction controller, added 4 optional positions for fault injection: U-phase current sensor, V-phase current sensor, W-phase current sensor in the three-phase current of motor stator and speed sensor.

For digital pulse fault in 3 type faults of traction controller, added 5 optional positions for fault injection: CIGBT1 on the A bridge, CIGBT2 on the A bridge, CIGBT3 on the A bridge, CIGBT4 on the A bridge of the three-level rectifier and speed sensor.

For register bit reversal fault in 3 type faults of traction controller, added 3 optional positions for fault injection: U-phase current sensor, V-phase current sensor, W-phase current sensor in the three-phase current of motor stator.

d) For open circuit fault of active device in 3 type faults of traction inverter, added 8 optional positions for fault injection: CIGBT1 on the A bridge, CIGBT2 on the A bridge, CIGBT3 on the A bridge, CIGBT4 on the A bridge of the three-level rectifier, IIGBT1 on the U bridge, IIGBT2 on the U bridge, IIGBT3 on the U bridge, IIGBT4 on the U bridge of the three-level inverter.

For open/short circuit fault of passive device in 3 type faults of traction inverter, added 4 optional positions for fault injection: the upper capacitor FC1 in the middle

DC link, the upper resistor DRe1 in the middle DC link, the lower capacitor FC2 in the middle DC link, the lower resistor DRe2 in the middle DC link.

5) Optimized operation interface.

Optimized and adjusted operation interface, the interface of this version is more friendly, and easier to operate, including:

a) Added the adaptive function of the interface at different screen resolutions.

b) Added waveform drag out interface function which is easier for the user to observe the simulation results.

c) Added One-click restart function.

The software has four basic functions, including:

1) User management: This is mainly used for management of the user name and password of the software user, as well as user additions and deletions;

2) Simulation platform setting: This is mainly used for simulation main circuit parameter setting and selection of simulation control strategy.

3) Fault injection simulation management: selection of fault injection module and fault injection method can be carried out, under the selected fault injection module and fault injection method, the type of fault can be selected, and location selection of fault injection and fault parameter setting for the corresponding fault.

4) Simulation results management: The user select the observation point according to the need. After the fault injection simulation, display the simulation results curve in the form of a single window, zoom in or zoom out simulation waveform and other operations. For real-time simulation data of electrical parameters in selected observation points, data can be saved and displayed in the form of data and data graphs. The basic functional diagram of the software is shown in Fig. 1.

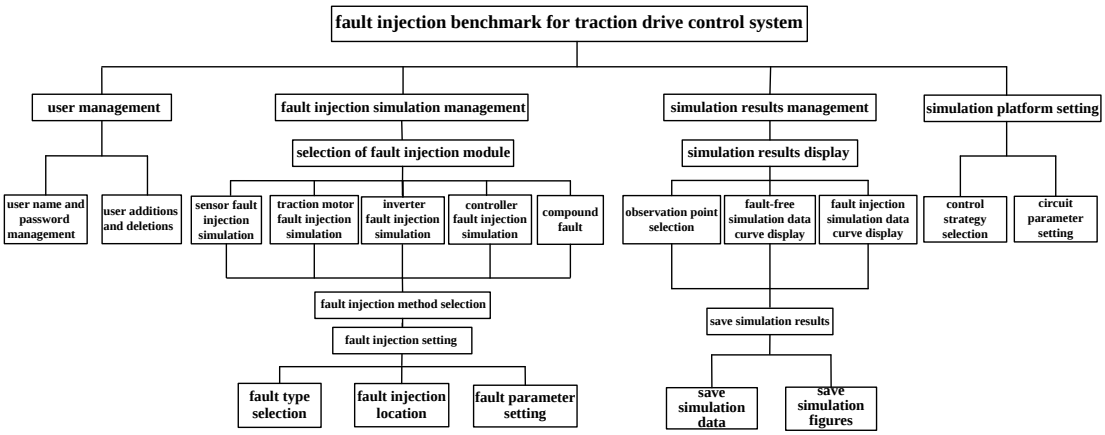


Fig .1 Basic functions of software schematic diagram

2 Fault injection benchmark hardware and software environment

2.1 Benchmark hardware

The hardware platform of the fault injection benchmark is a computer, and the computer configuration requirements are as follows:

1) CPU frequency 2.6 GHz;

2) Hard disk 128 GB;

3) Memory (RAM) 4GB.

2.2 Benchmark software

1) Fault injection benchmark running platform: Microsoft Windows 7 flagship version 64 bit.

2) Software development platform: Matlab 2014a.

2.3 Fault injection simulation platform and fault injection benchmark

Fault injection control system fault injection simulation platform based on fault injection benchmark consists of traction drive system model based on Simulink, control strategy and fault injection benchmark. Fault injection benchmark is built based on three fault injection methods:

1) Fault injection method based on signal conditioning. Based on this method, 20 fault types for four fault injection, which are modules sensors, traction converter, traction motor and traction controller are realized, as shown in Fig. 2.

2) Fault injection method based on mixture of signal conditioning and model replacement. Based on this method, 3 fault types for traction inverter are realized, as shown in Fig. 3.

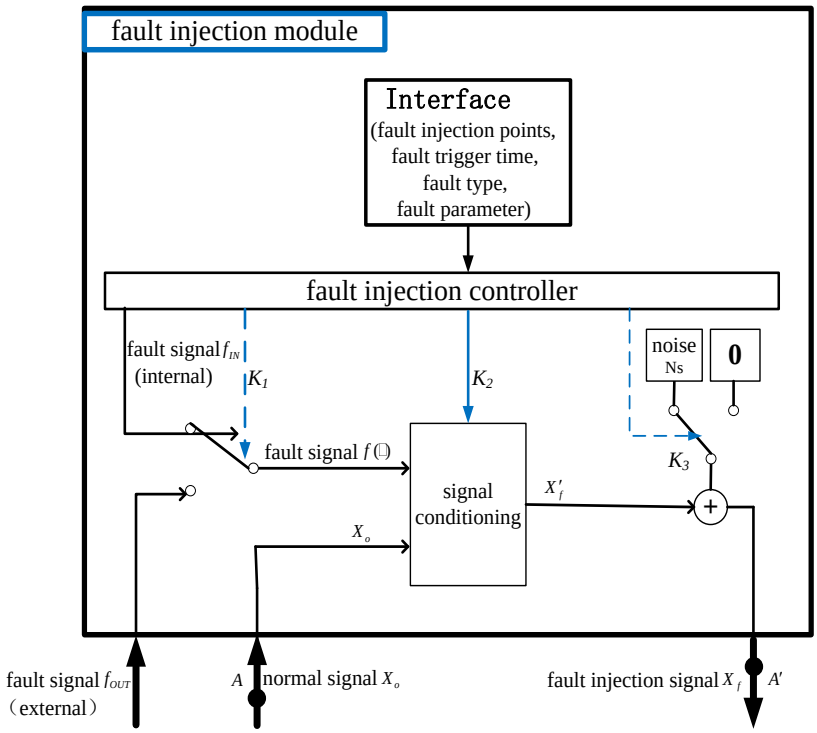


Fig .2 Fault injection method based on signal conditioning

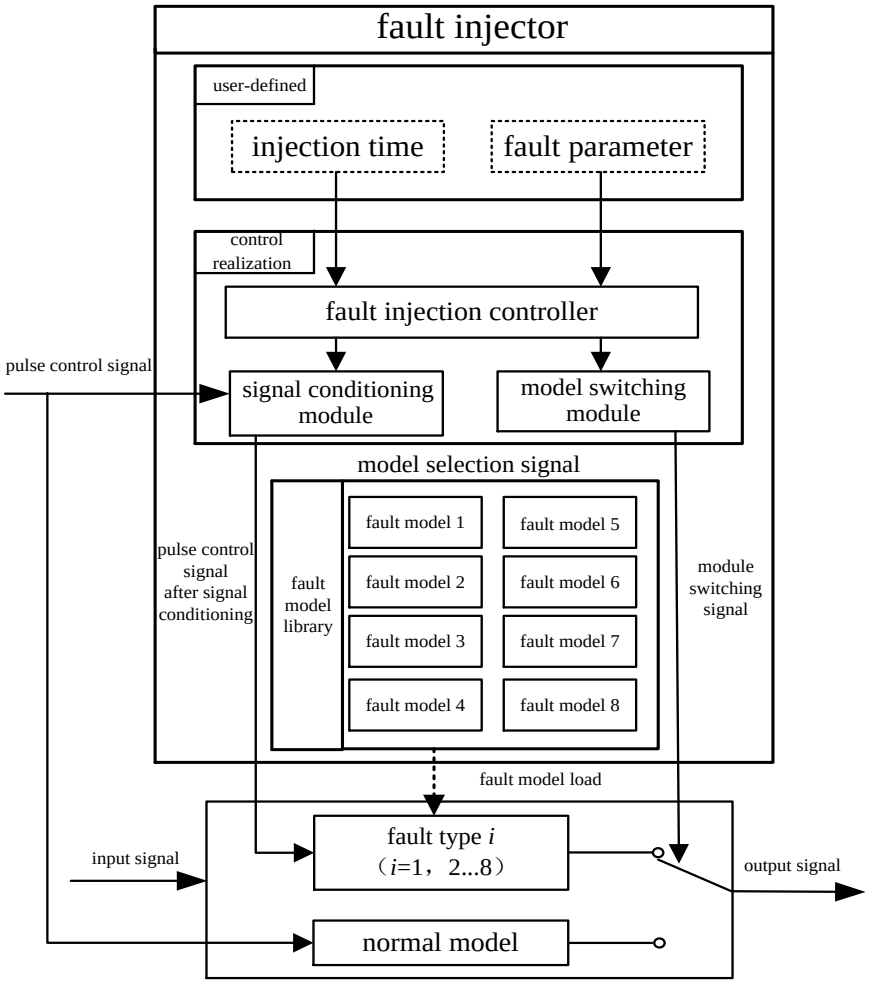


Fig .3 Fault injection method based on mixture of signal conditioning and model replacement

3 Fault injection benchmark instruction

3.1 How to use the software?

This section aims to clarify the use of the software (benchmark) and enumerates several frequently asked questions about solutions.

1) Before the user starts the software, please make sure the following requirements are satisfied:
   - Operating environment: it is recommended to use Matlab2014a or advanced version;
   - The working directory location: the path name cannot have a space character, Chinese characters and special characters. For example, the executable file with a path name ‘C\TDCS-FIB\CRH2.exe’ can run, but the one with ‘C\TDC S-FI B\CRH2.exe’ not, because the path name contains a space character.
2) Double-click ‘CRH2.exe’ in the ‘TDCS-FIB’ folder to start the software. Note that the first time running costs a little bit more time, please keep its running without any other operations.
3) Some of the buttons on the software will have to wait for a while before clicking on the next step. For example, when you click the ‘Fault-Free Simulation’ button in the drop-down list box, the software will automatically open the simulation model and modify it. Please wait for the simulation model to shut down automatically and proceed to the next step. After clicking the ‘Start Simulation’ button on the toolbar, the simulation takes some time, so please wait for the simulation to complete, do not click the relevant button, otherwise, it will cause an error.
4) If the software is in use, the error or a long time can not get the simulation results, please try to shut down the software and restart.
5) If the simulation is running, Matlab appears similar to the error shown in Fig. 4,

please open the CRH2forBenchmark_Copy.slx file under the TDCS-FIB(V2.0)\Data\，and refer to Fig. 5 and Fig. 6 for the solution to modify the related settings. Close the software and restart it after the completion of modification.

```
错误使用 Benchmark>SimulatePushButton_Callback (line 2271)
The block diagram 'CRH2forBenchmark' uses bus signals. However, the 'Mux blocks used to create bus signals'
diagnostic is not configured to 'error'. To prevent modeling errors:

(1) Open Upgrade Advisor and run the 'Check for Mux blocks used to create bus signals' check.
(2) Follow the recommendations from this check to make your model compliant.

Error while evaluating uicontrol Callback
```

Fig. 4 An error occurs during simulation

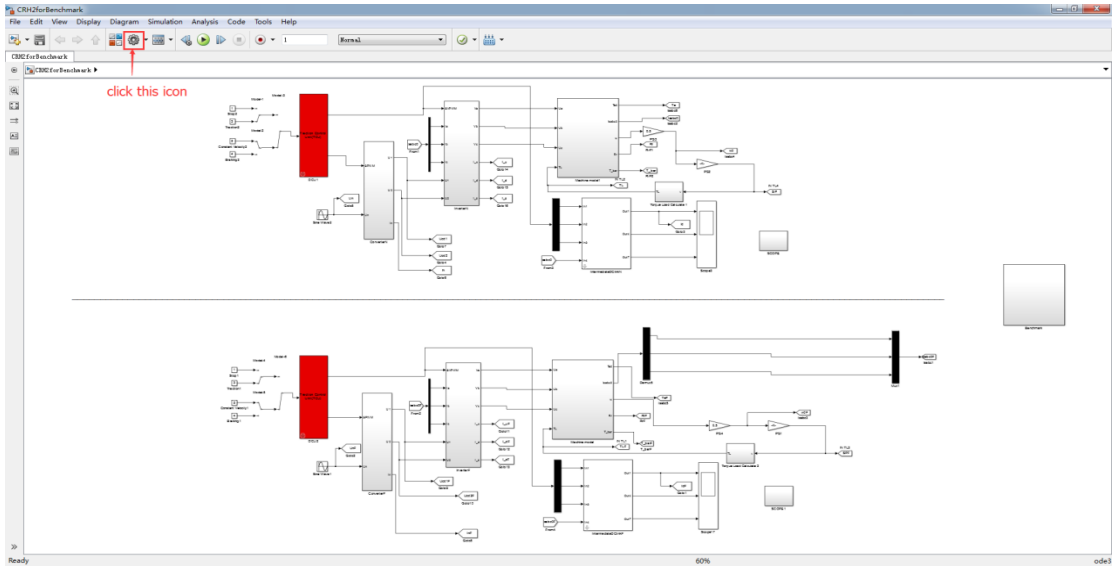


Fig. 5 Step 1 of solution

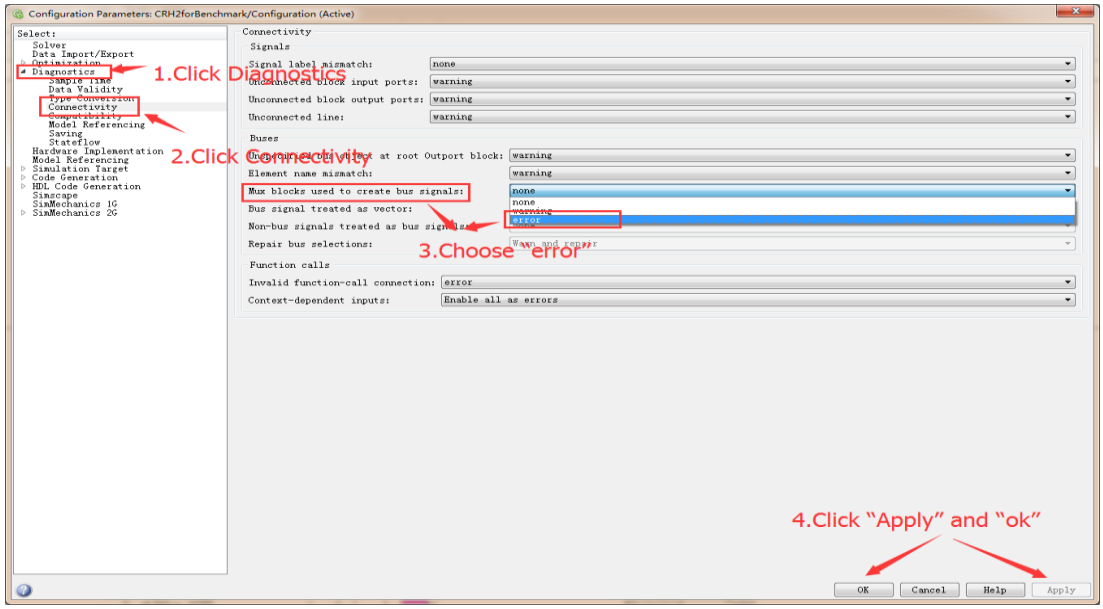


Fig. 6 Step 2 of solution

6) If there are other unknown errors, please try to shut down the software and then restart it.

3.2 System login

Double-click this software, first, the initial interface appears as shown in Fig. 7.

Fig. 7 Software initialization

After completing the software initialization, the system login screen appears as shown in Fig. 8.

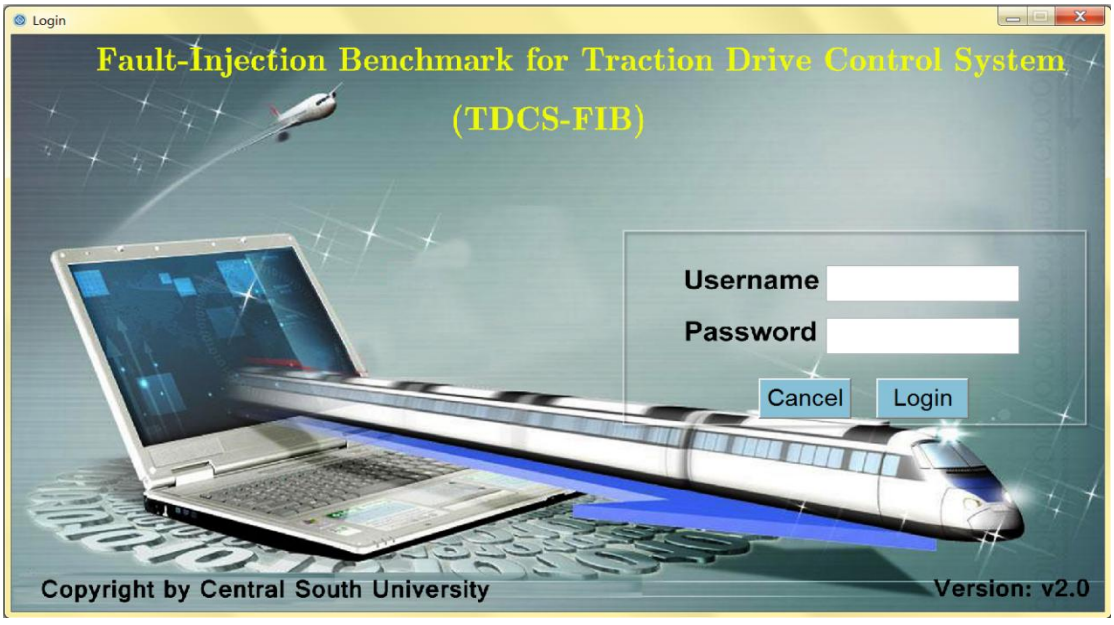


Fig. 8 System login screen

In order to ensure the security of the system, the user can only login in the system with correct user name and password. If the password is wrong, the system will alarm a prompt as shown in Fig. 9. If you do not want to login the system, please click 'Cancel'.

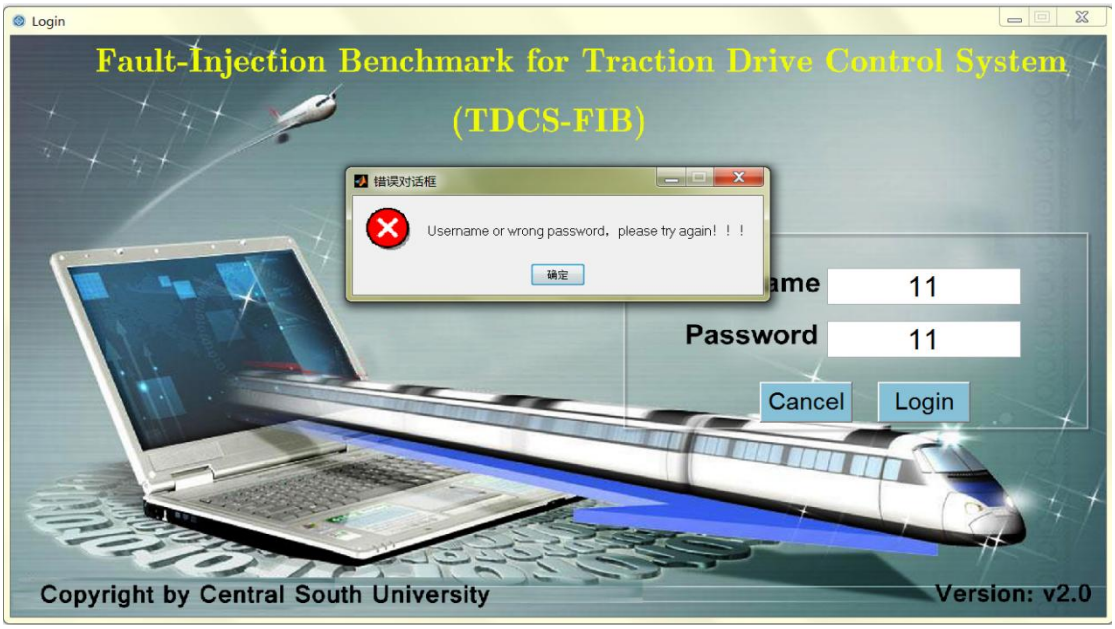


Fig. 9 Password error

Enter the correct user and password, click 'Login', then it will pop-up the main interface of fault injection benchmark, which is the system main interface as shown in Fig. 10.

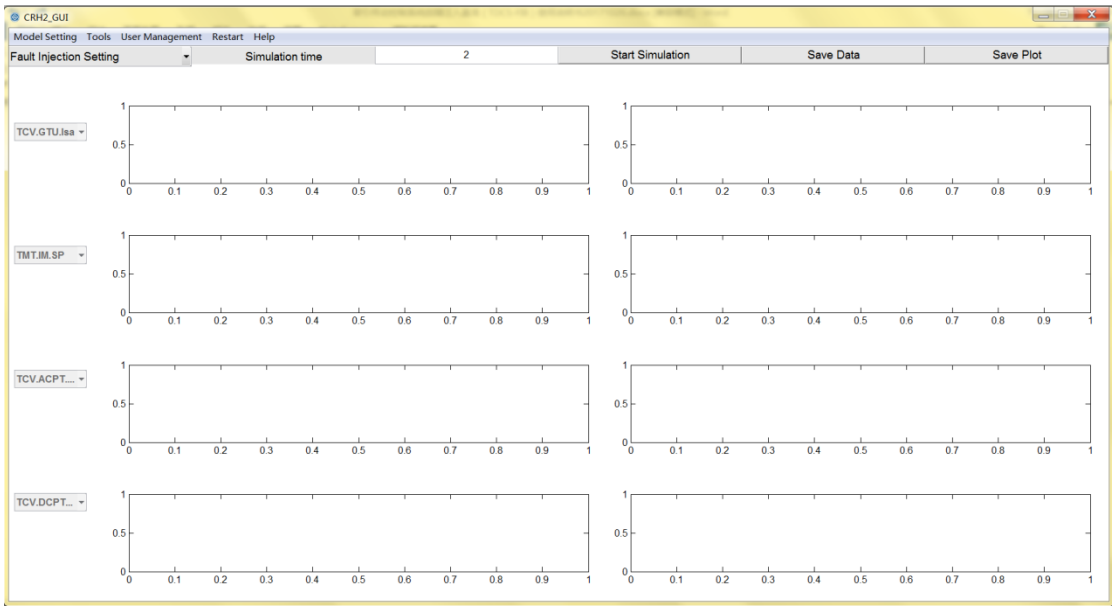


Fig. 10 The main interface of the fault injection benchmark

3.3 System main interface

The main interface includes the main menu bar, toolbar and simulation results display area as shown in Fig. 10. The main menu bar includes several functions such as model setting, tools, user management and help. The toolbar includes 5 buttons, which are the Fault Injection Setting, Simulation Time, Start Simulation, Save Data and Save Plot. The simulation results display area is used for the selection of the observation point and the display of the simulation results.

3.4 Main menu bar

1) Click the ‘Model Setting’ drop-down menu in the main menu bar, then it will show the ‘Model Parameter Setting’, ‘Control Strategy Setting’ and ‘Main Circuit Topology’ options as shown in Fig. 11.

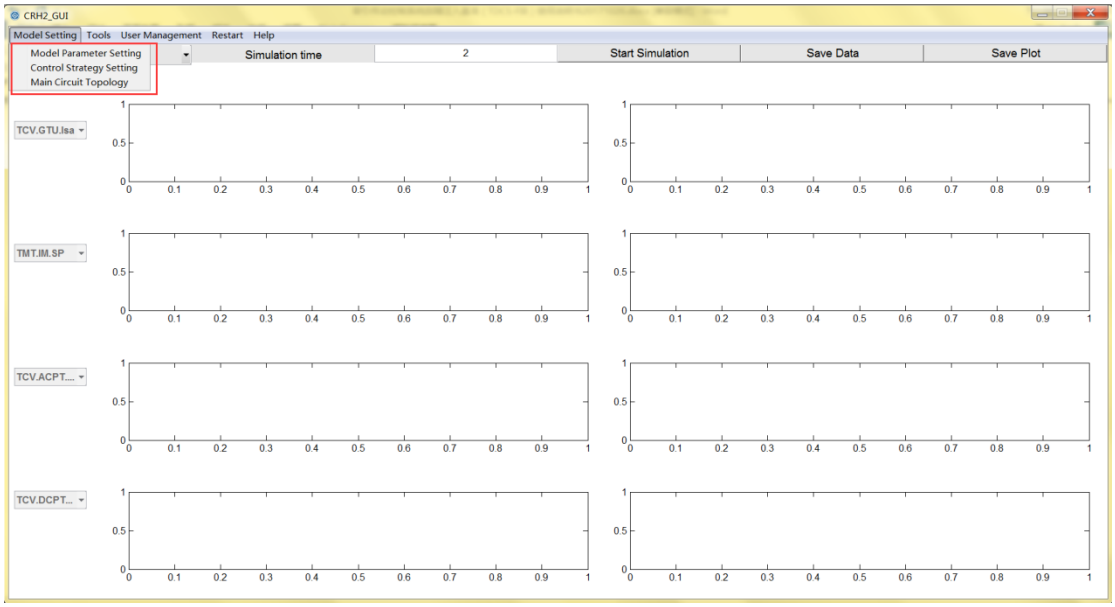


Fig. 11 Model setting

Click the ‘Model Parameter Setting’ option of the ‘Model Setting’ drop-down menu, the user can set or change the main circuit parameters, as shown in Fig. 12. Set or change is completed, click ‘Apply Current Parameters’ to save the current parameters setting; and then click ‘Save’, the parameter settings are complete. To restore the

default parameters, click the ‘Reset Default Parameters’ button and then click the ‘Apply Current Parameters’ button.

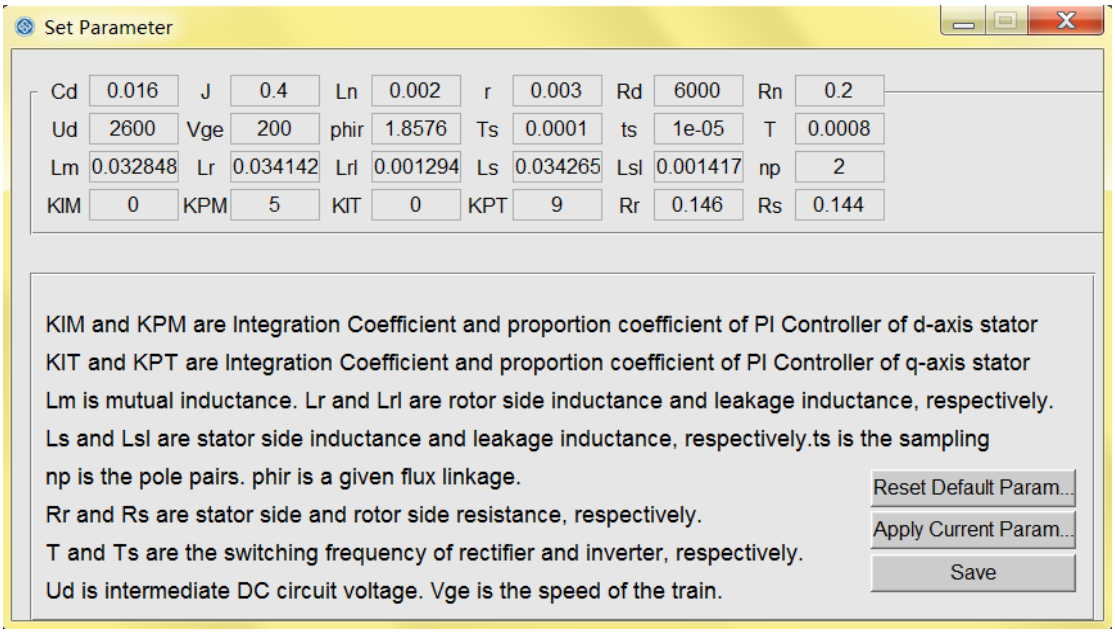


Fig. 12 Model parameter setting

Click the ‘Control Strategy Setting’ option of the ‘Model Setting’ drop-down menu, it will pop up the main circuit diagram, the user can set the control strategy of the main circuit, as shown in Fig. 13. The user can manually replace the red part (control strategy module) of Fig. 13, then save the change.

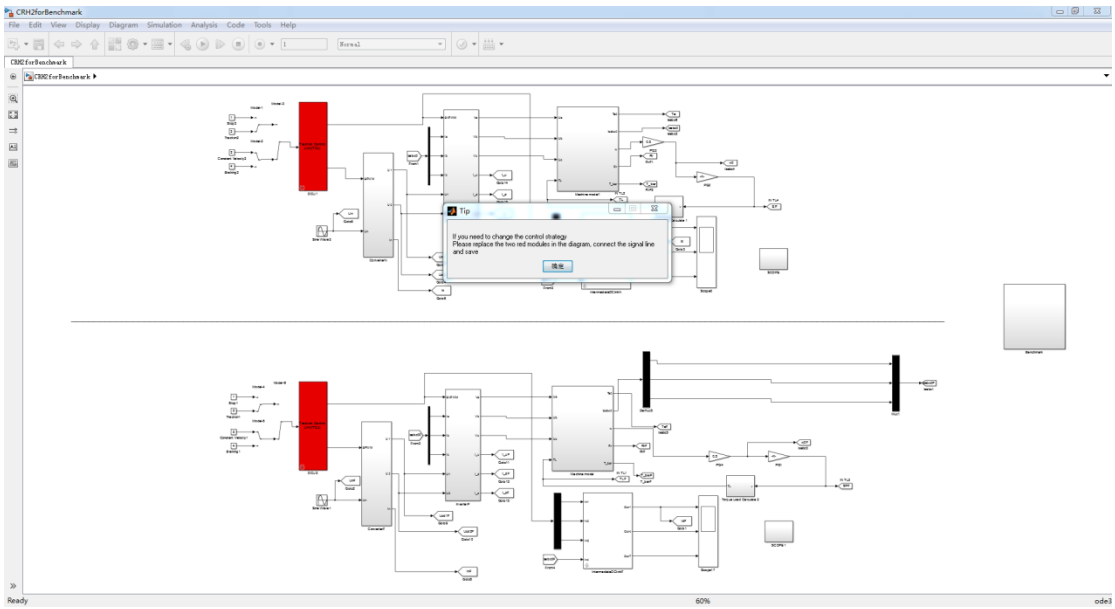


Fig. 13 The main circuit and control strategy selection

Click the ‘Main Circuit Topology’ option of the ‘Model Setting’ drop-down menu, the user can view the main circuit topology, and the circuit topology is shown in

Fig. 14.

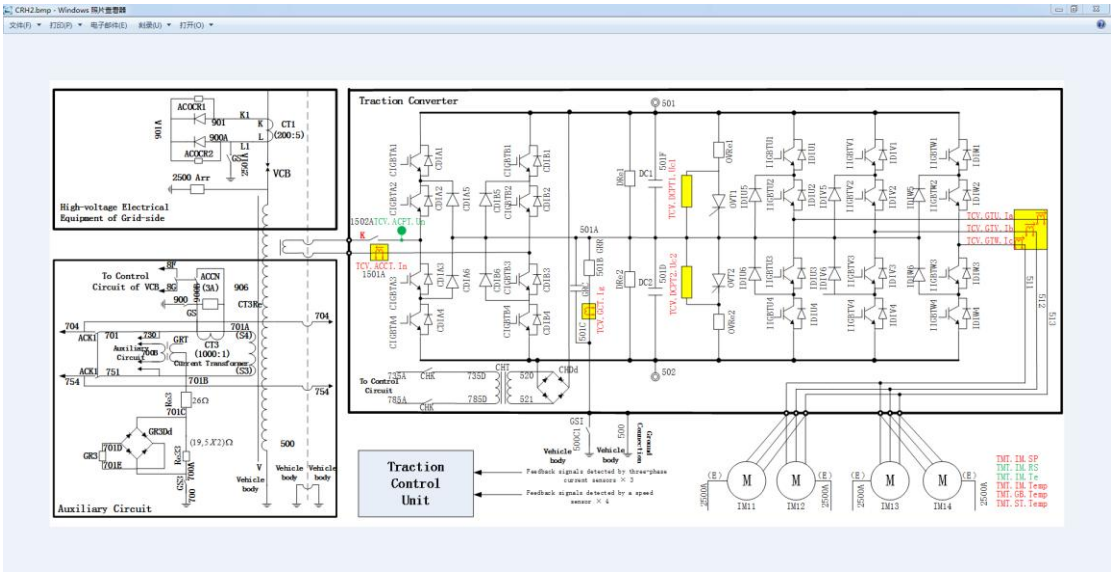


Fig. 14 The main circuit topology

2) Click the ‘Tools’ drop-down menu in the main menu bar, it appears ‘Zoom in’, ‘Zoom out’, and ‘Pan’ option as shown in Fig. 15. The user can select any of the three options, and then place the mouse on the image you want to see, then you can view the zoom in or out or pan simulation results curve, user-friendly data and simulation results for analysis. If you click ‘Zoom in’, the amplifying waveform will appear as shown in the upper left comer of Fig. 16.

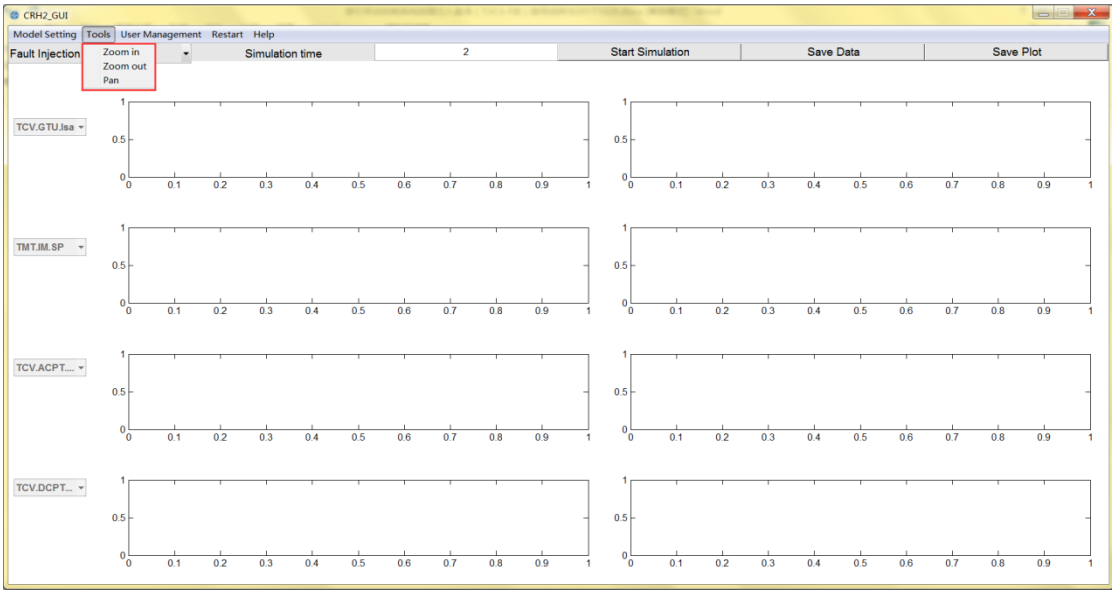


Fig. 15 Tools

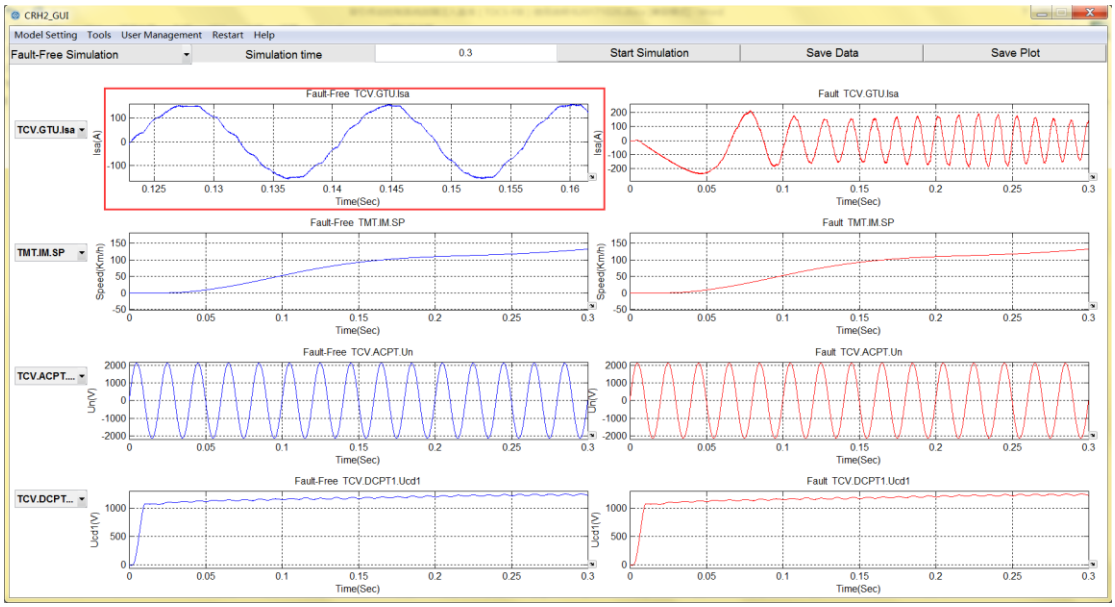


Fig. 16 Zoom in

Click the in the bottom right corner of the waveform, it will pop-up waveform drag interface as shown in Fig. 17, which makes it easier for users to view and adjust the waveform. The menu bar of waveform out interface provides the users with the 'Tools' and 'Edit' two drop-down menus, where the 'Tools' drop-down menu is the same as the 'Tools' drop-down menu in the main interface. The 'Edit' drop-down menu is used to adjust the color and scope of the waveform.

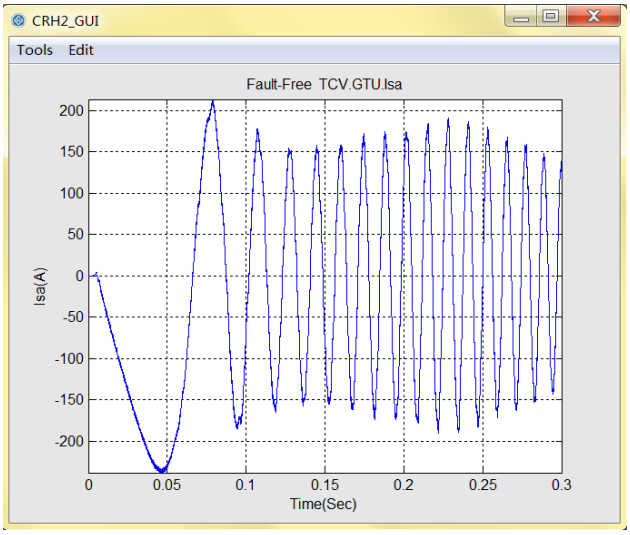


Fig. 17 Waveform drag interface

3) Click the 'User Management' drop-down menu in the main menu bar. There are three options: 'Add User', 'Default User' and 'Delete User', as shown in Fig. 18. The users can choose one of the three options to add or delete or default user account. If

the ‘Add User’ option is selected, a dialog box appears as shown in Fig. 19, you can add the user account; and then click ‘Save’ to add a new user, otherwise, click ‘Cancel’. If only one user account exists, the function of ‘Delete User’ is unavailable, as shown in Fig. 20.

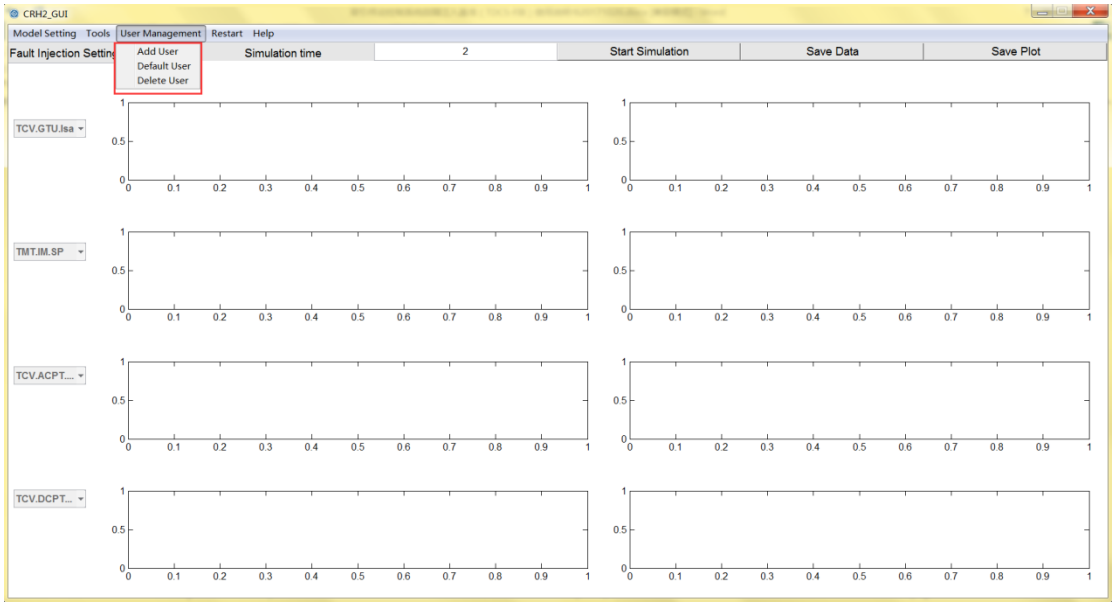


Fig. 18 User management

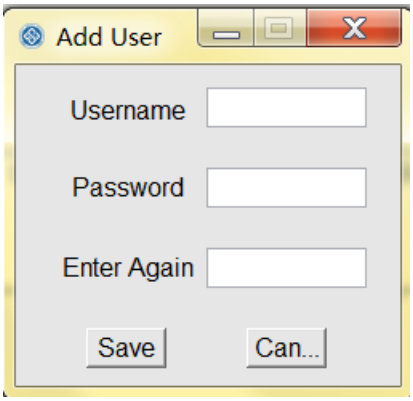


Fig. 19 Add user

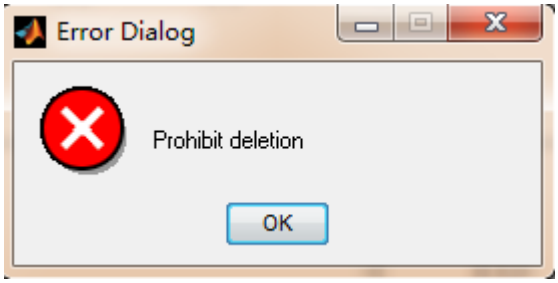


Fig. 20 Error dialog

4) Click the ‘Restart’ menu in the main menu bar, the software will restart and enter the main interface.

5) Click the ‘Help’ drop-down menu in the main menu bar, there are two options: ‘Help Document’ and ‘About TDCS-FIB’ will be shown in Fig. 21. Select the ‘Help Document’ option, you can view the usage of the software and some common problems as shown in Fig. 22.

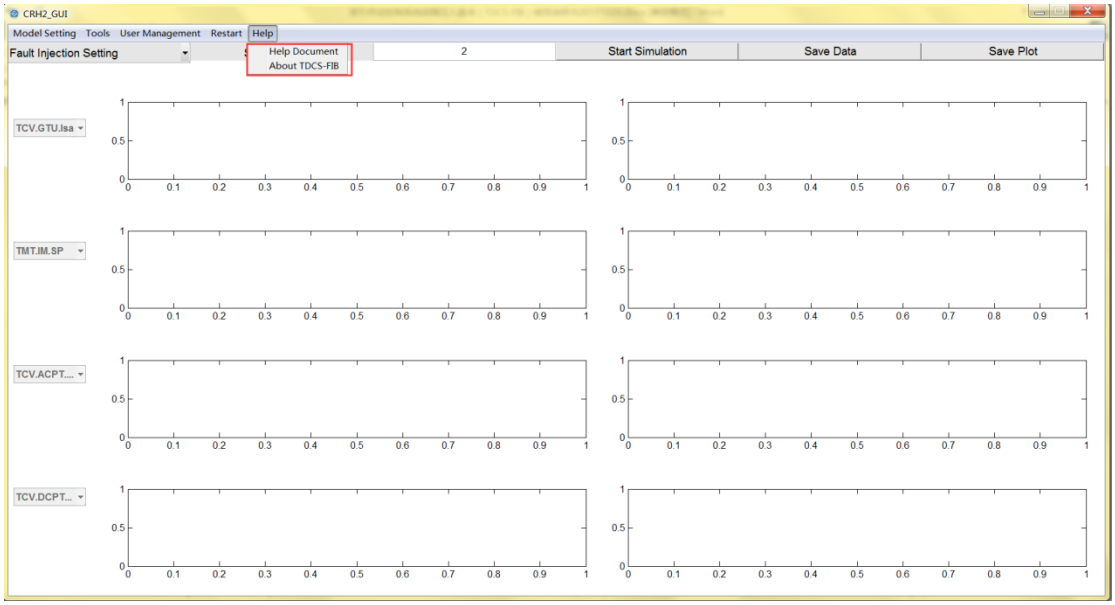


Fig. 21 Help

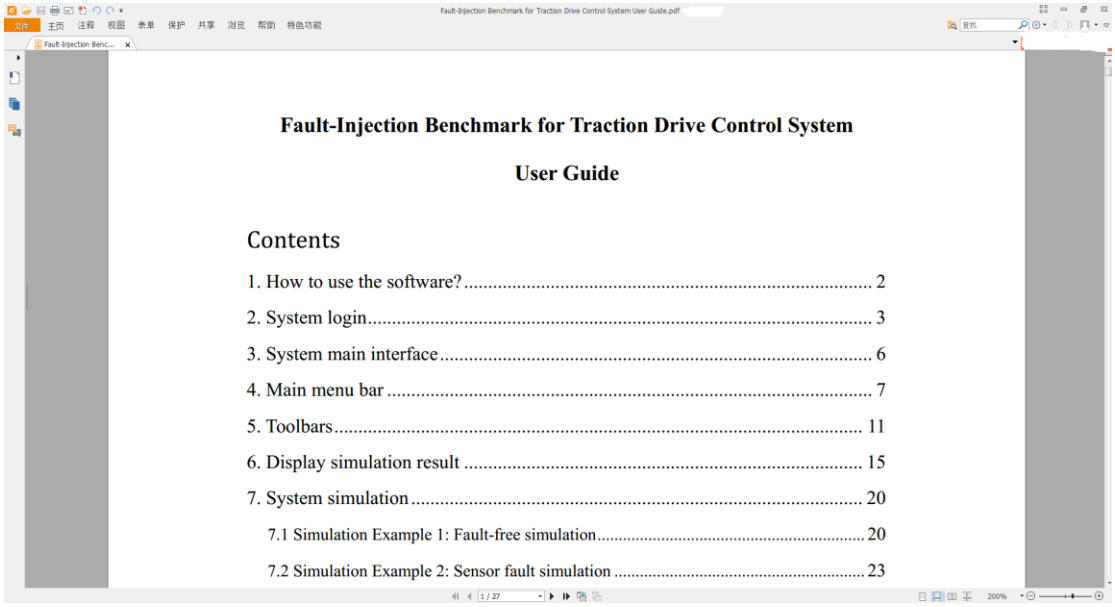


Fig. 22 Help Document

Click on the ‘About TDCS-FIB’ option, the window appears as shown in Fig. 23, which displays the version number, copyright information and the website of the

copyright unit. In Fig. 23, click the CSU page and the Team page, it will directly jump to the browser and open the corresponding page.

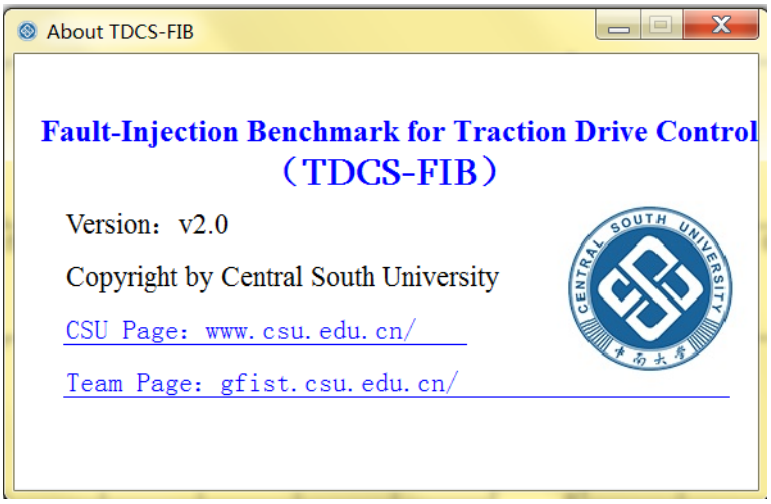


Fig. 23 About TDCS-FIB

3.5 Toolbars

Click the ‘Fault Injection Setting’ of toolbars, it pops up five options: ‘Fault-Free Simulation’, ‘Sensor Fault Injection Setting’, ‘Motor Fault Injection Setting’, ‘TCU Fault Injection Setting’ and ‘Converter Fault Injection Setting’ as shown in Fig. 24. Click one of the five options to enter the corresponding failure mode parameter settings.

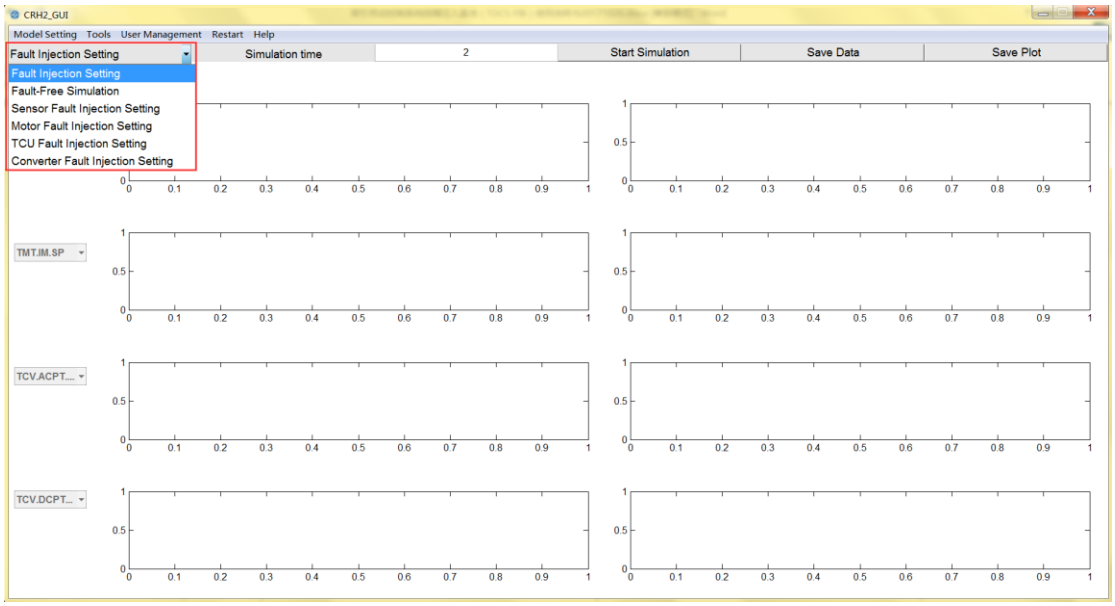


Fig. 24 Options in ‘Fault Injection Setting’

Click the ‘Sensor Fault Injection Setting’ option, pop up the Sensor Fault Injection (SFI) parameter setting interface as shown in Fig. 25. Click the ‘drop-down’ button next to the right of the ‘Fault Type’. The drop-down list box displays 13 sensor fault type options, including normal mode (fault-free injection) and 12 sensor faults, as shown in Fig. 26.

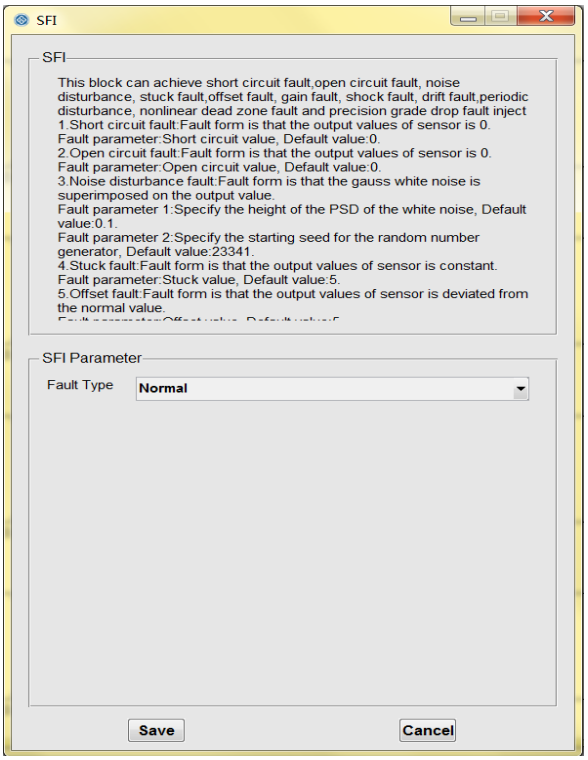


Fig. 25 Sensor fault injection parameter setting

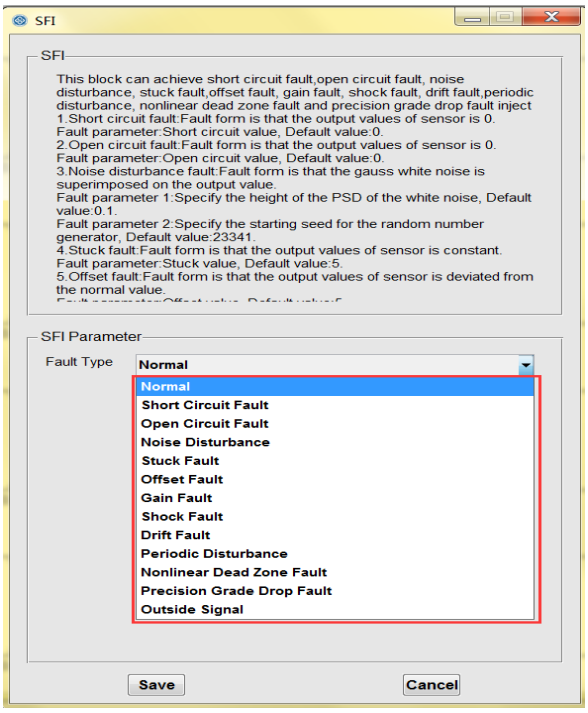


Fig. 26 Sensor fault type selection

Click the ‘Motor Fault Injection Setting’ option, it will pop up the ‘Motor Fault Injection (MFI) parameter setting interface as shown in Fig. 27. Click the ‘drop-down’ button next to the right of the ‘Fault Type’. The drop-down list box displays 7 motor fault type options, including normal mode (fault-free injection) and 6 sensor faults, as shown in Fig. 28. Select any of these options, the corresponding fault of motor failure can be injected in the system. There is a check box for adding noise in the MFI method selection, if the user wants to add noise interface, please check ‘Noise Disturbance’, otherwise there is no noise interface.

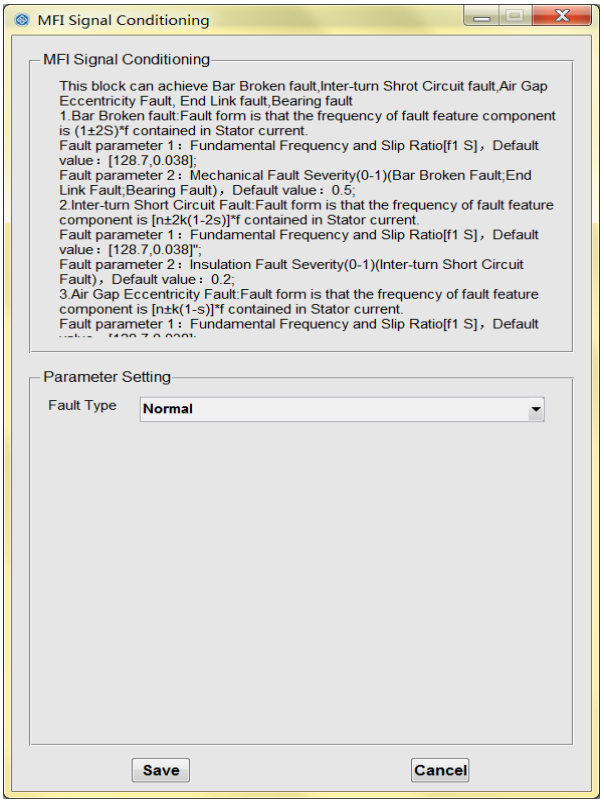


Fig. 27 Motor fault injection parameter setting

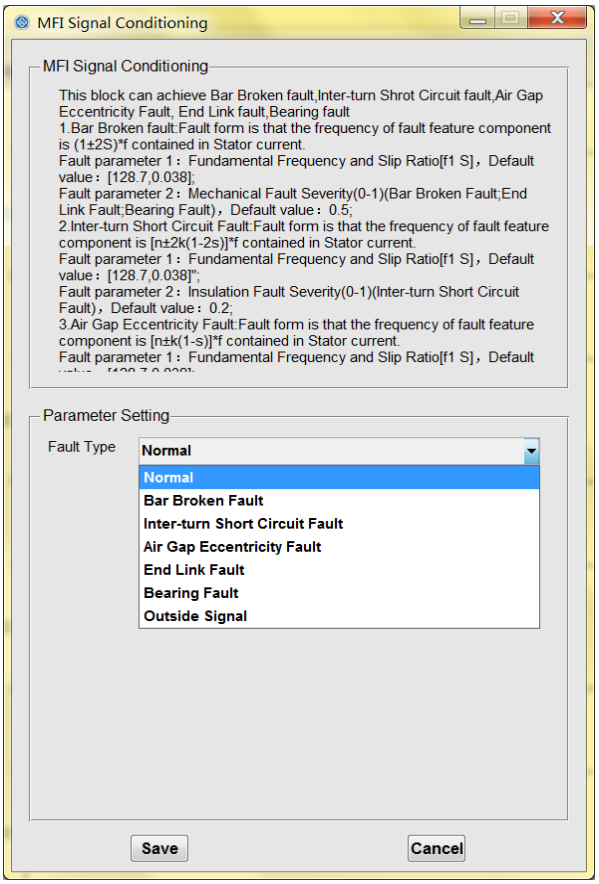


Fig. 28 Motor fault type selection

Click the ‘TCU Fault Injection Setting’ option, pop up the TCU Fault Injection (TFI) parameter setting interface as shown in Fig. 29. Click the ‘drop-down’ button next to the right of the ‘Fault Type’. The drop-down list box displays 5 TCU fault type options, including normal mode (fault-free injection) and 4 sensor faults, as shown in Fig. 30. Select any of these options, the corresponding fault of TCU failure can be injected in the system. There is a check box for adding noise in the TFI selection, if the user wants to add noise interface, please check ‘Noise Disturbance’, otherwise there is no noise interface.

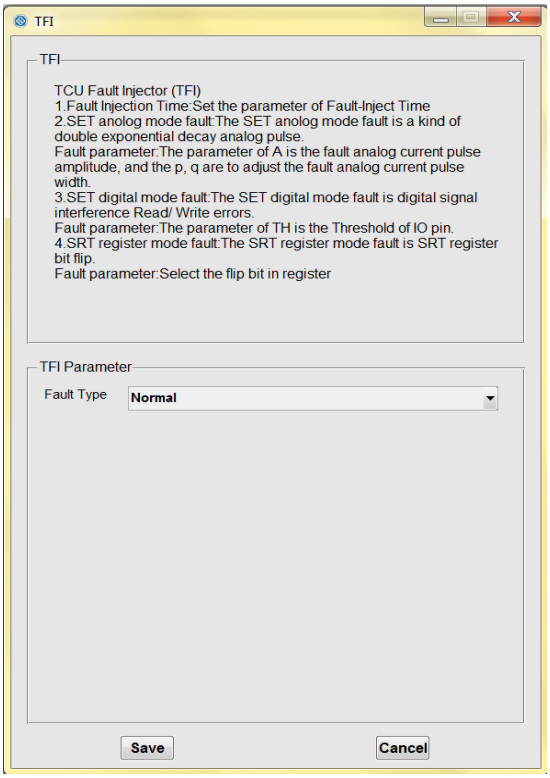


Fig. 29 TCU fault injection parameter setting

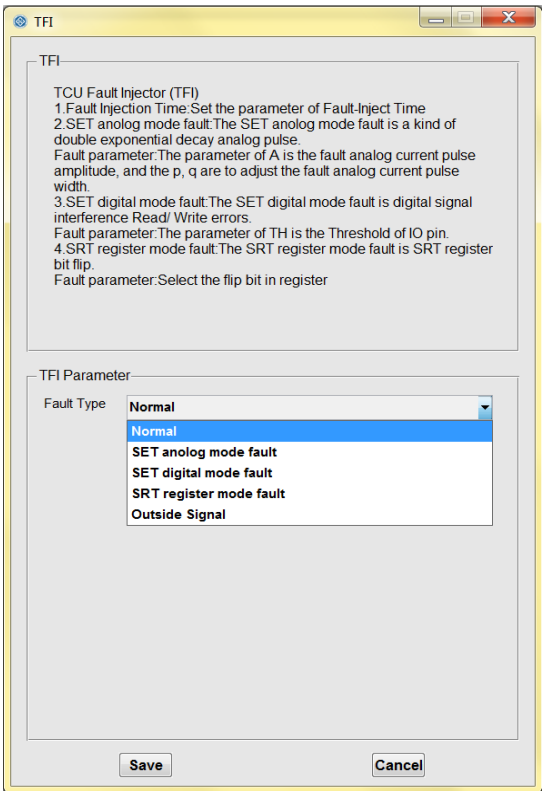


Fig. 30 TCU fault type selection

Click the ‘Converter Fault Injection Setting’ option, pop up the CFI prompt interface as shown in Fig. 31. Prompt users: The fault injection method based on signal conditioning and model replacement mixture, which realize 3 converter faults, including Power Device Periodic Fault, Passive Device Open/Short Fault and Performance Degradation Fault. Click the ‘OK’ option in Fig. 31, pop up the CFI parameter setting interface as shown in Fig. 32. Click the ‘drop-down’ button next to the right of the ‘Fault Type’. The drop-down list box displays 5 converter fault type options, including normal mode (fault-free injection) and 4 converter faults, as shown in Fig. 33. Select any of these options, the corresponding fault of converter failure can be injected in the system. There is a check box for adding noise in the CFI selection, if the user wants to add noise interface, please check ‘Noise Disturbance’, otherwise there is no noise interface.

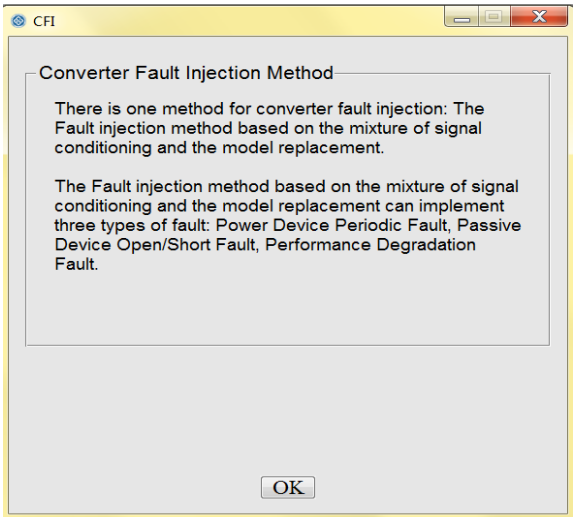


Fig. 31 Converter fault prompt interface

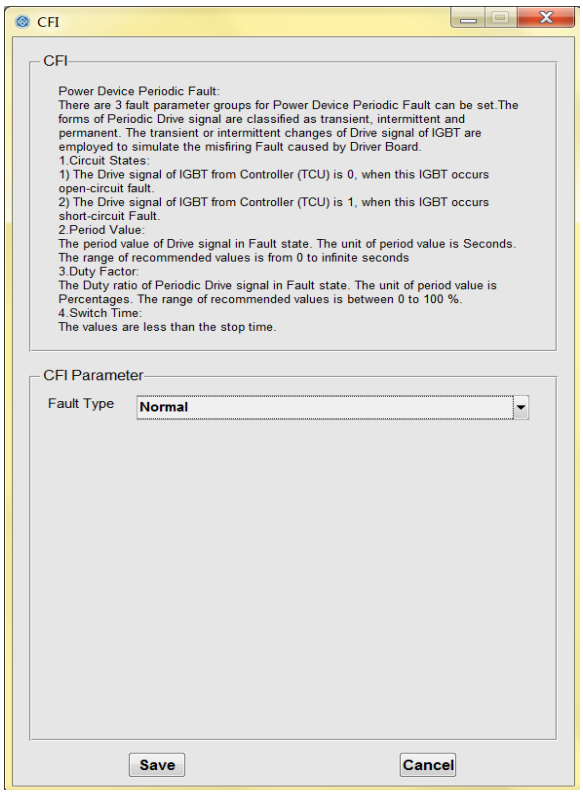


Fig. 32 Converter fault injection parameter setting

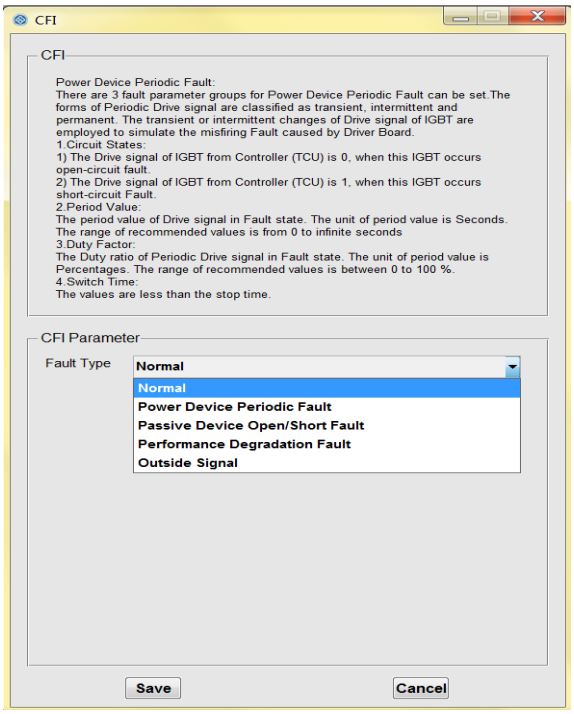


Fig. 33 Converter fault type selection

2) After selecting the fault to be injected, the user also needs to enter the fault injection time and fault injection parameter setting. Take the ‘Short Circuit Fault’ of the sensor as an example, if ‘Short Circuit Fault’ selected, fault type selection will pop up the ‘Fault inject Time’ column menu and ‘Fault Injection Location’ drop-down menu as shown in Fig. 26, the users need to enter the fault injection time (in seconds) and select the fault injection location in the column. As shown in the red box in Fig. 34, fault injection time is 1 second and the fault injection position is ‘U-phase in the three-phase current of the inverter’.

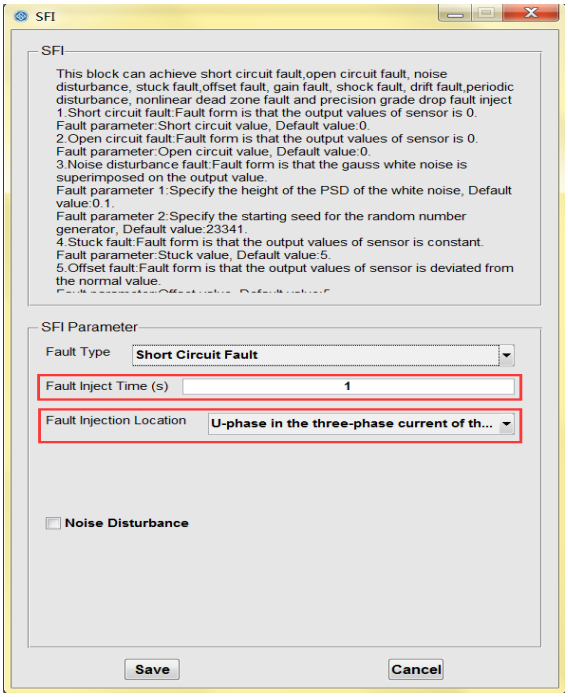


Fig. 34 Fault injection time setting

After setting the fault injection parameter, the simulation duration should also be set. The required simulation time (in seconds) is on the right of the ‘Simulation time’ button, as shown in the red box in Fig. 35, the simulation duration is 2 seconds.

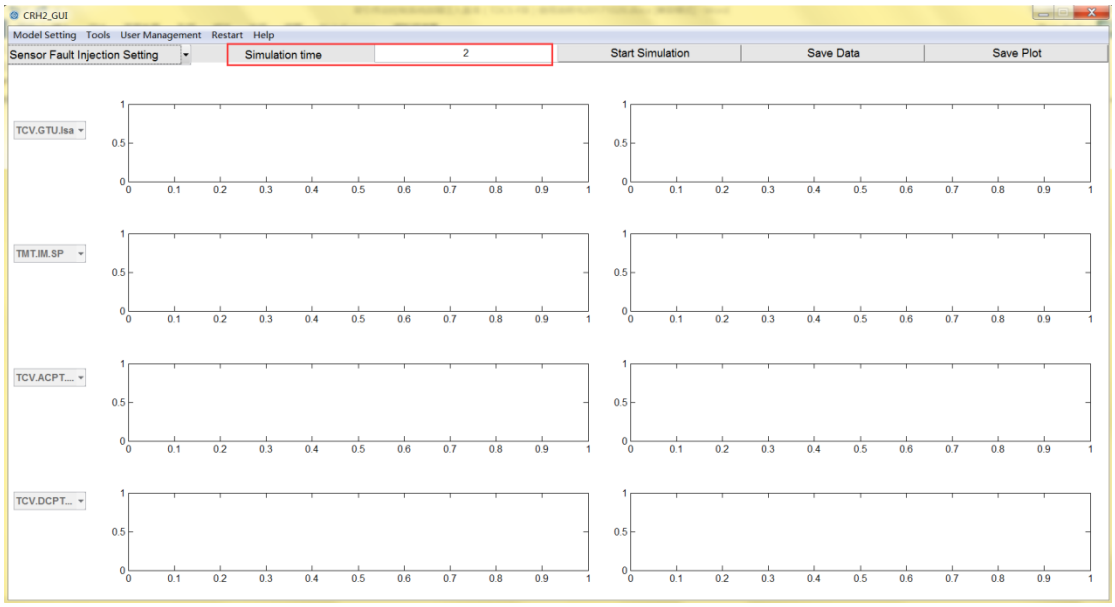


Fig. 35 Simulation duration setting

3) After setting the simulation duration, click the ‘Start Simulation’ button to start the simulation of the selected fault injection mode. Before the end of the simulation, the ‘Start Simulation’ button changes to ‘Please Wait!’ as shown in Fig. 36.

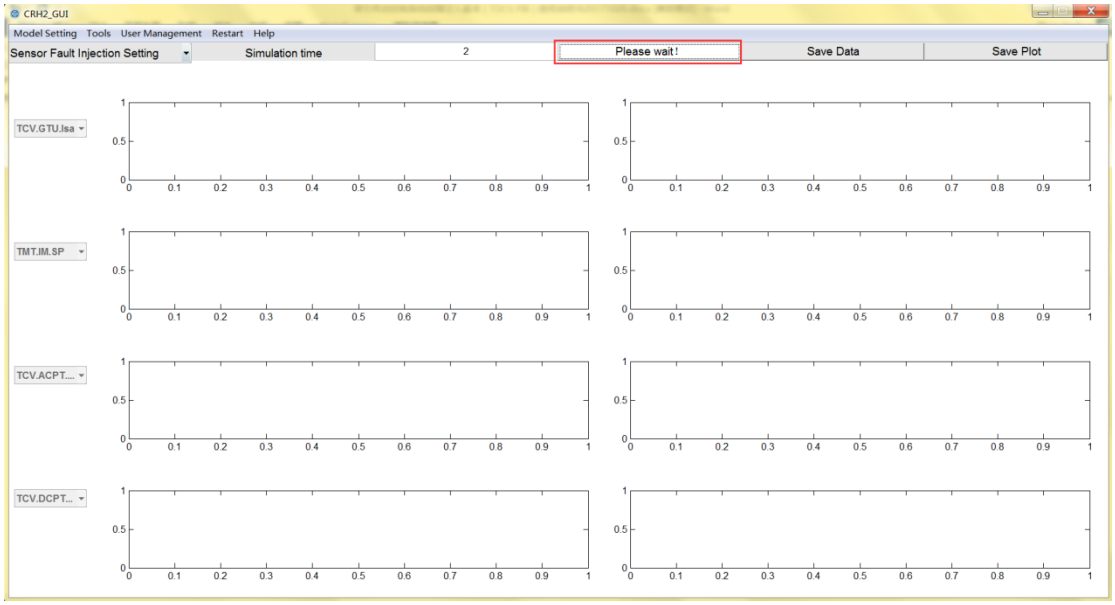


Fig. 36 Start of simulation

When the prompt of ‘Please wait!’ Changes back to ‘Start Simulation’, the simulation ends.

4) After the simulation, click the ‘Save Data’ button on the toolbar, it will pop-up the data save window, as shown in Fig. 37.

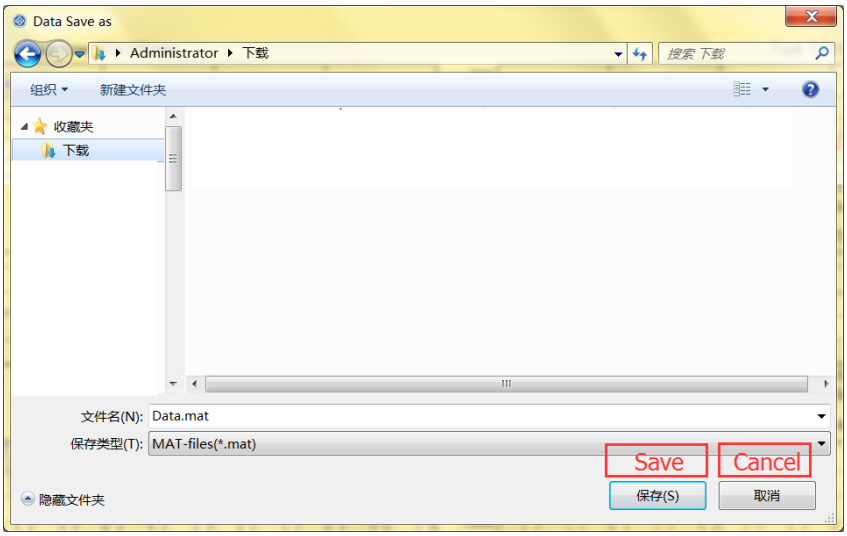


Fig. 37 Save data

The simulation data is saved as mat file. Note that there will be an error when no simulation data are generated as shown in Fig. 38. Click the ‘OK’ button, and return to the system main interface.

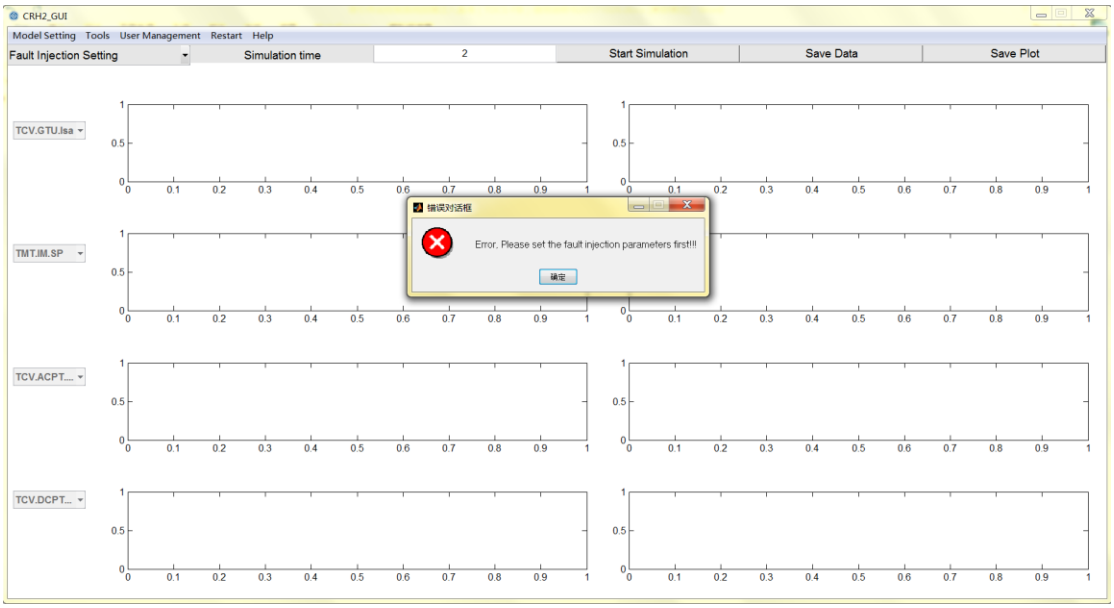


Fig. 38 Save data error

5) Click the ‘Save Plot’ button, it will pop-up the ‘Save Plot’ window, as shown in Fig. 39.

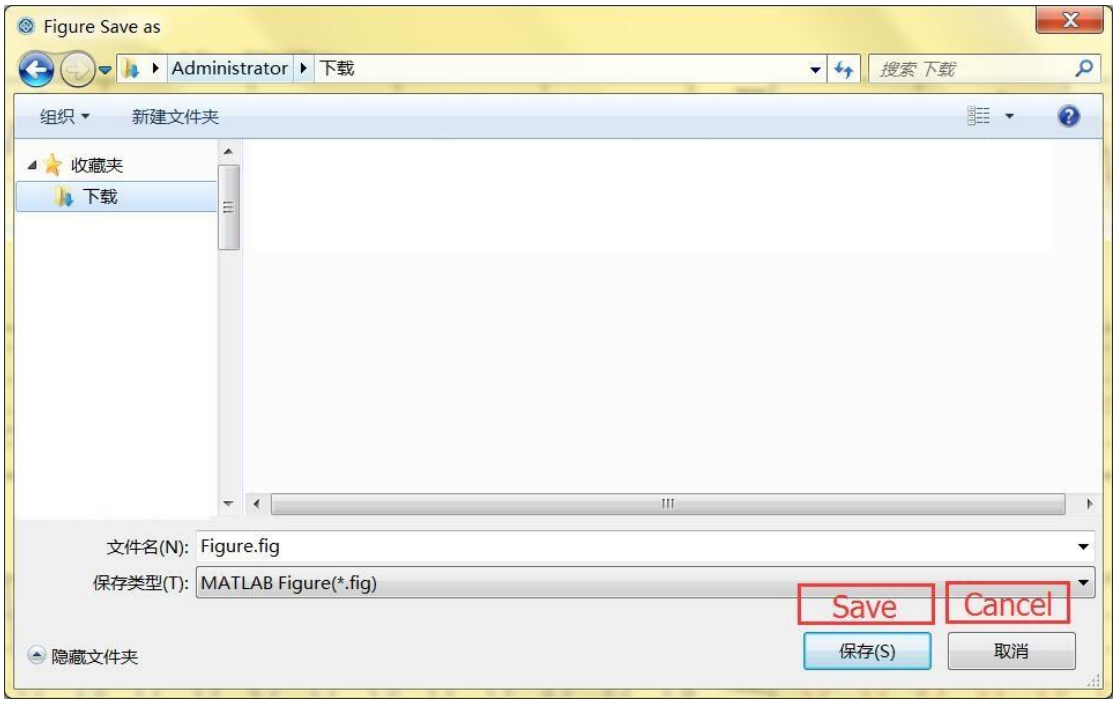


Fig. 39 Save simulation figure

Based on user demands, the users can select four formats for the simulation waveform to be saved, which are fig format, jpg format, eps format, bmp format, the

result is shown in Fig. 40.

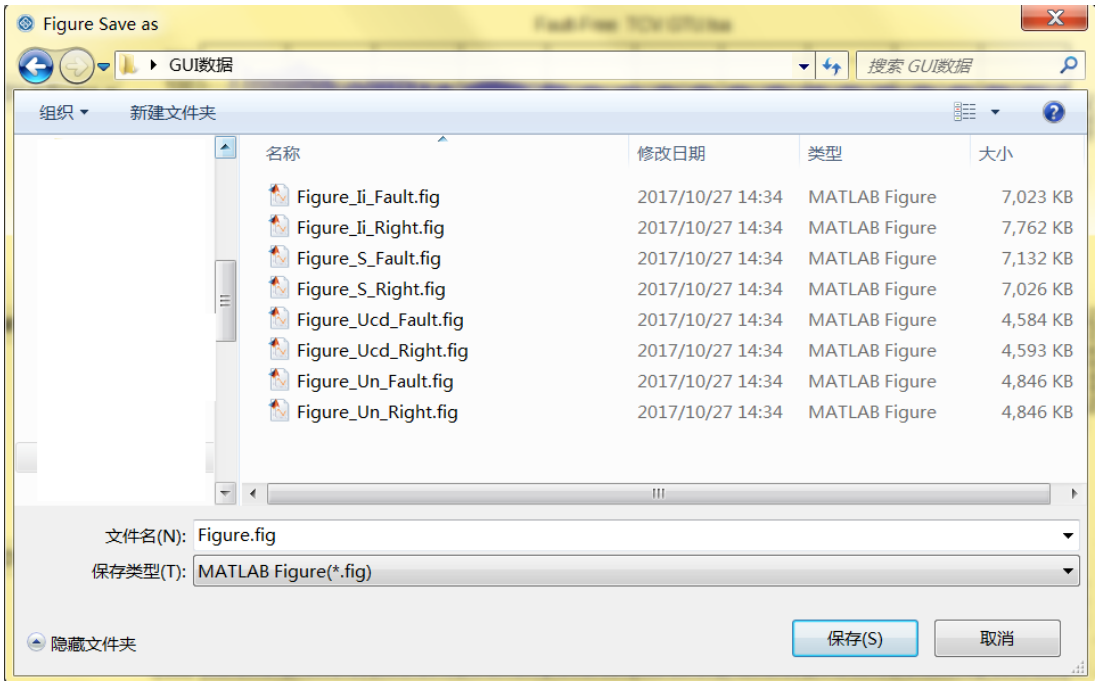


Fig. 40 Save plot results

If no fault injection simulation is carried out, no simulation image. An error will be alarmed when the user clicks to save the simulation waveform, as shown in Fig. 41. Click the ‘OK’ button, and return to the system main interface.

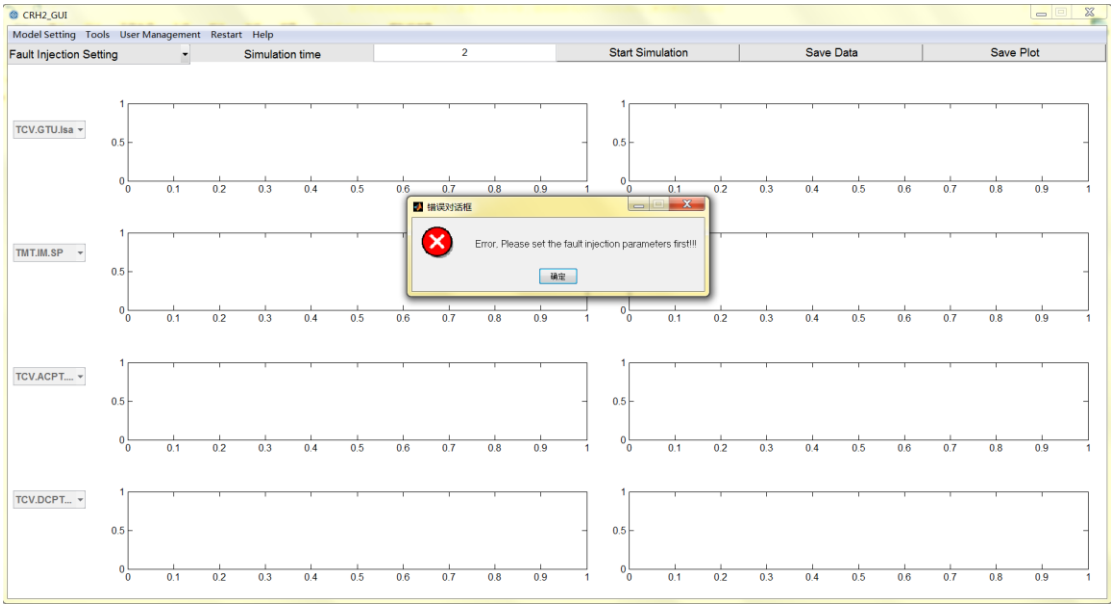


Fig. 41 Error when saving simulation plot

3.6 Display simulation result

Simulation results display areas are divided into three regions, from left to right, including the selection area of observation points, fault-free injection simulation results display area and fault injection simulation result display area, as shown in Fig .42.

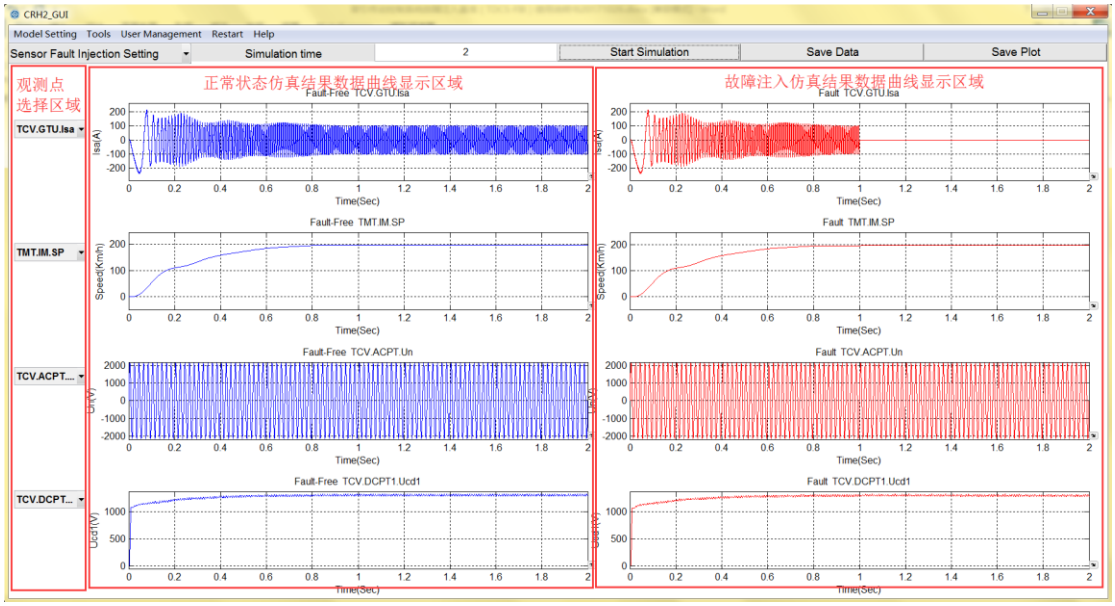
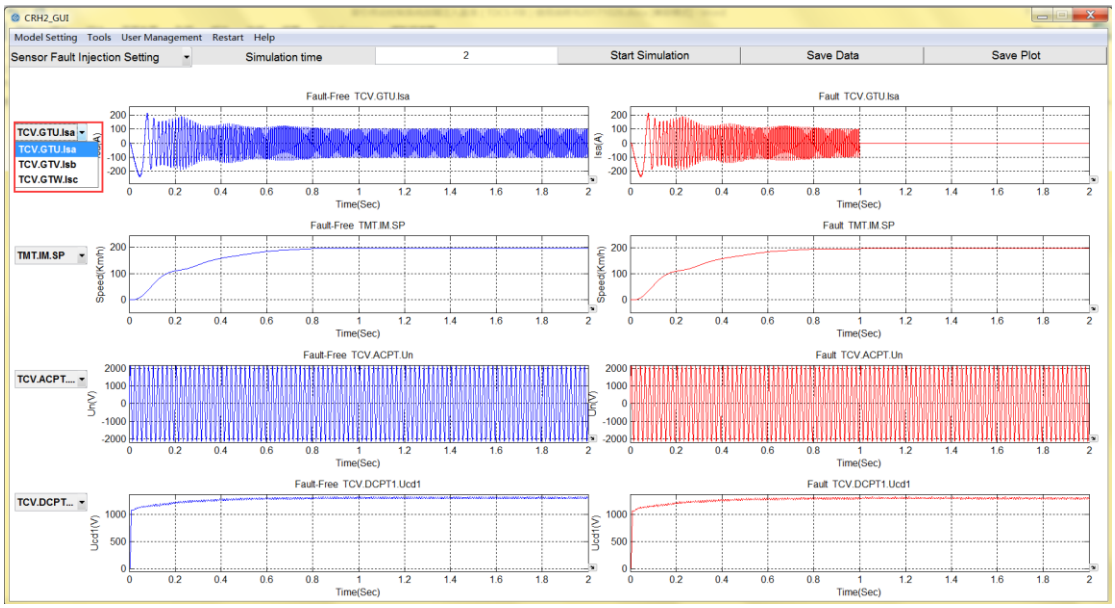


Fig. 42 Simulation result display areas

The data curve of four observation points can be displayed in the display area at the same time. Based on different demands, the users can select different observation points to observe the simulation data curve of normal operation and simulation data curve after fault injection. In the observation point selection area, there are four observation points from top to bottom, select the drop-down list box, and click any drop-down button of the list box, the user can select the corresponding observation points.

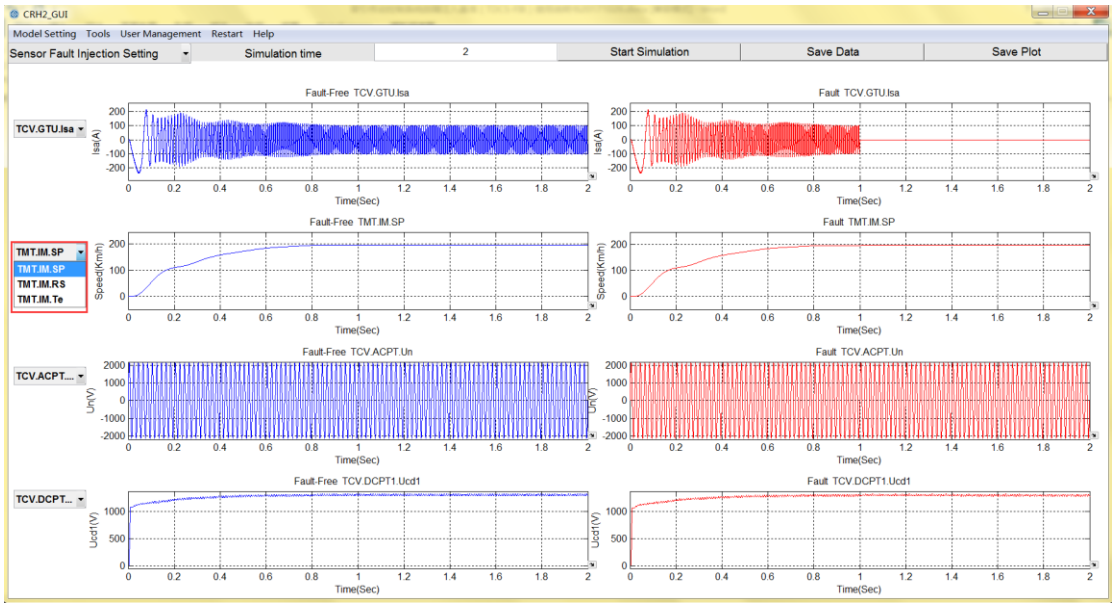
In the first observation point drop-down list box, the user can select three observation points, including ‘TCV.GTU.Isa’, ‘TCV.GTU.Isb’ and ‘TCV.GTU.Isc’, which are used to observe the current output of a, b, c three-phase in inverter. If TCV.GTU.Isa is selected, the curve of the output current of a-phase observation point in the normal mode and the curve of the output current of a-phase observation point in

fault mode are shown on the right of the observation point drop-down list box, as shown in Fig. 43 (a).



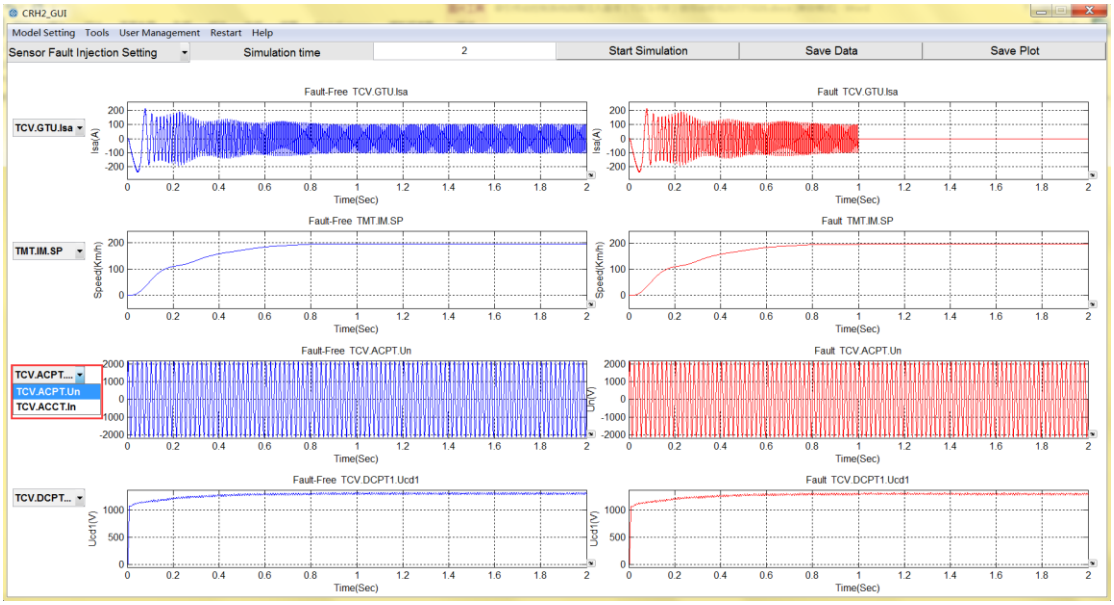
(a)

The second drop-down list box provides three observation points, including ‘TMT.IM.SP’, ‘TMT.IM.Rs’ and ‘TMT.IM.Te’, which are set observation points at the output port of the traction motor to observe running speed, motor speed and motor electromagnetic torque of train. If ‘TMT.IM.SP’ is selected, the right side of the observation point drop-down list box are the curve of the train running speed in the normal mode and after the fault injection, as shown in Fig. 43 (b).



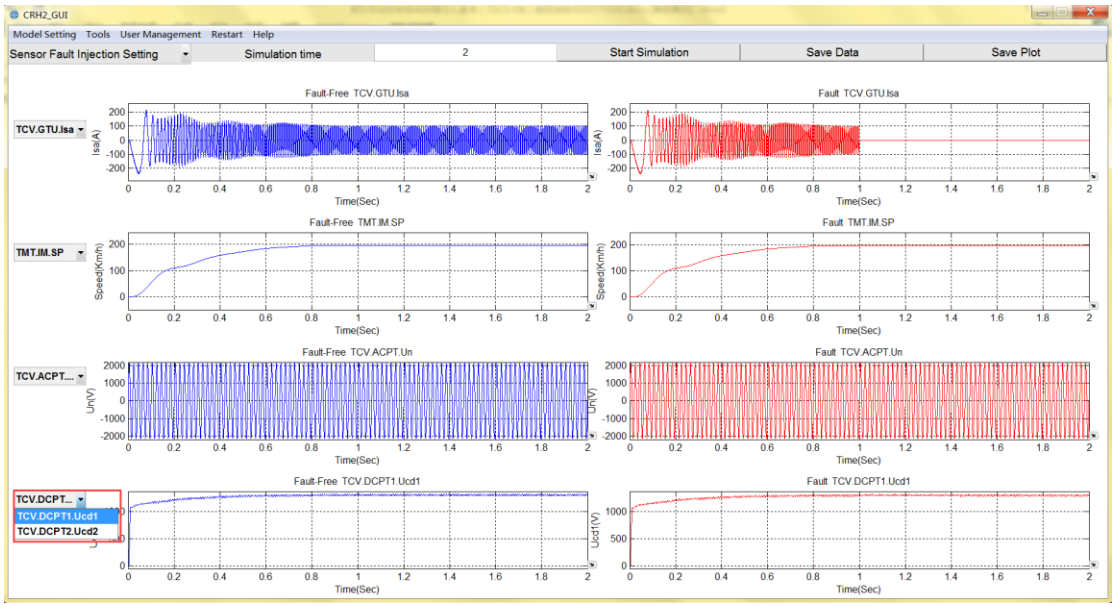
(b)

The drop-down list box in the third observation point provides two observation points, including ‘TCV.ACPT.Un’ and ‘TCV.ACCT.In’, which are set in the transformers secondary side to observe the output of AC voltage and the output of AC current. If ‘TCV.ACPT.Un’ is selected, the right side of the observation point drop-down list box are the curves of the transformers secondary side AC voltage in the normal mode and in fault mode, as shown in Fig. 43 (c).



(c)

The drop-down list box in the fourth observation point provides two observation points, including ‘TCV.DCPT1.Ucd1’ and ‘TCV.DCPT2.Ucd2’, which are set in the DC link to observe the voltage output on the upper and lower support capacitor. If ‘TCV.DCPT1.Ucd1’ is selected, the right side of the observation point drop-down list box are the curves of the voltage of supporting capacitor on the DC link in the normal mode and after the fault injection, as shown in Fig. 43 (d).



(d)

Fig. 43 Simulation results observation point selection

3.7 System simulation

3.7.1 Simulation Example1：Fault-free simulation

①Login the software and select ‘Fault-Free Simulation’ (click the button and wait a minute) as shown in Fig. 44.

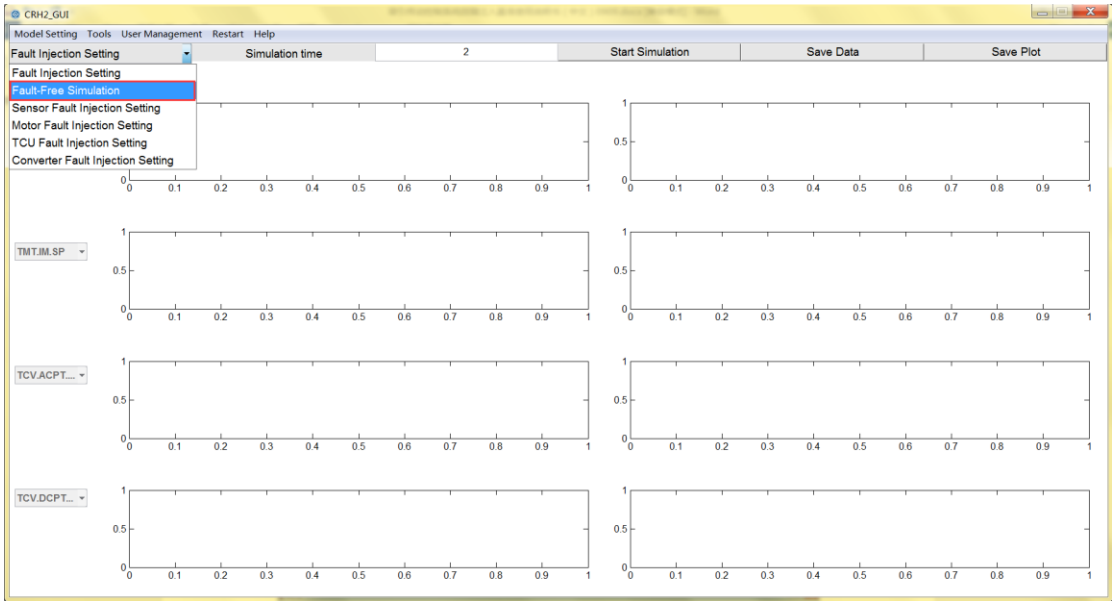


Fig. 44 Select fault-free simulation

②Set the simulation time, the simulation duration to be 0.3s, as shown in Fig. 45.

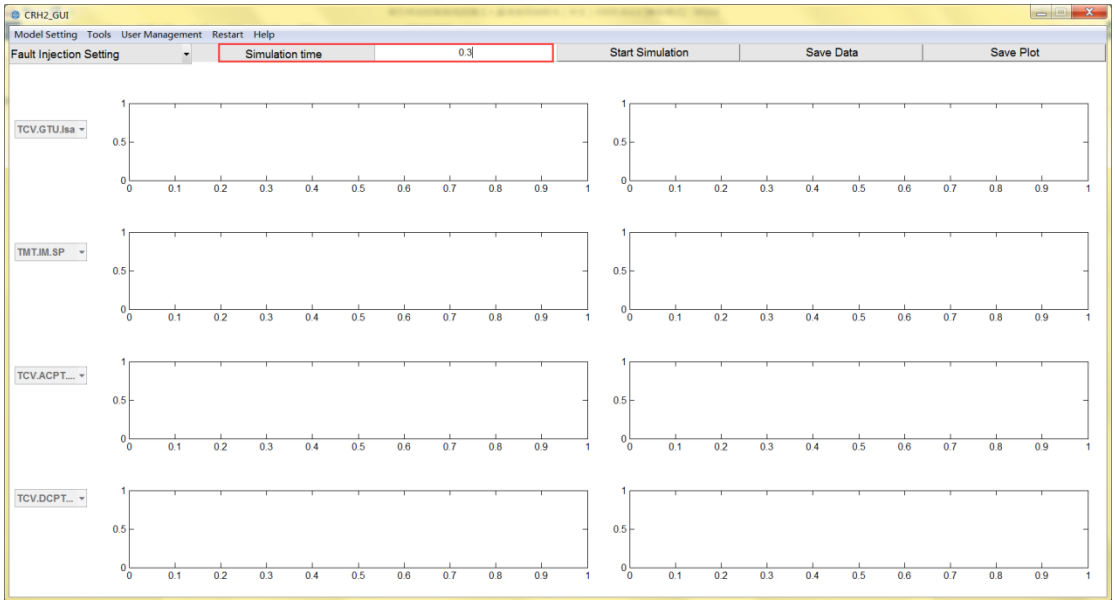


Fig. 45 Set simulation time

③Click the ‘Start Simulation’ button to start the simulation, as shown in Fig. 46.

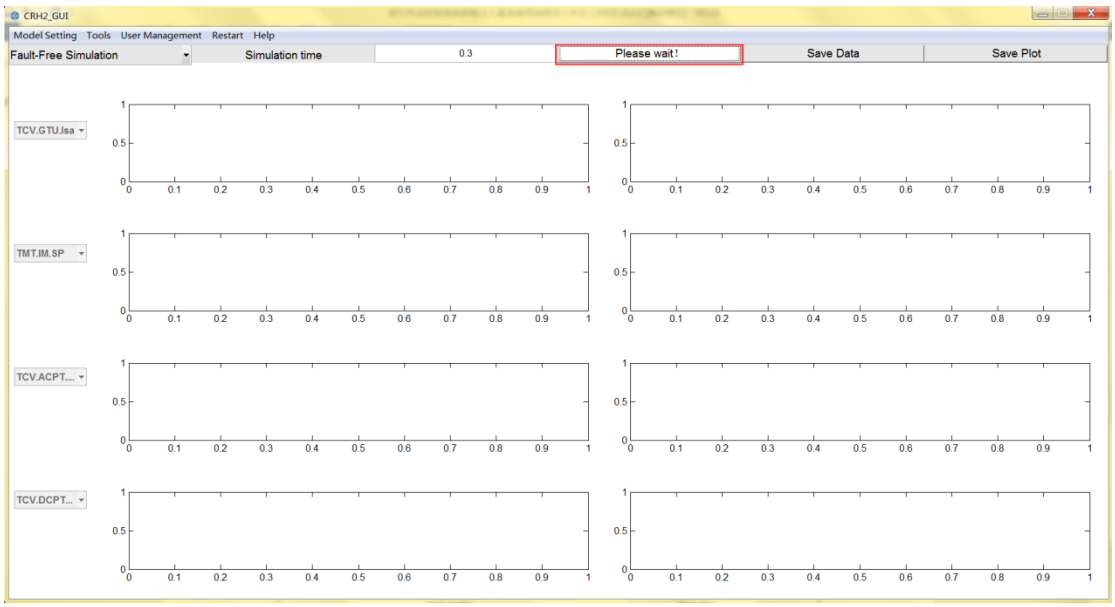


Fig. 46 In the simulation

④Output simulation waveform, the left column are the normal waveforms, the right column are the fault waveforms. No fault simulation, the left and right two waveforms are exactly the same, except for the color, as shown in Fig. 47.

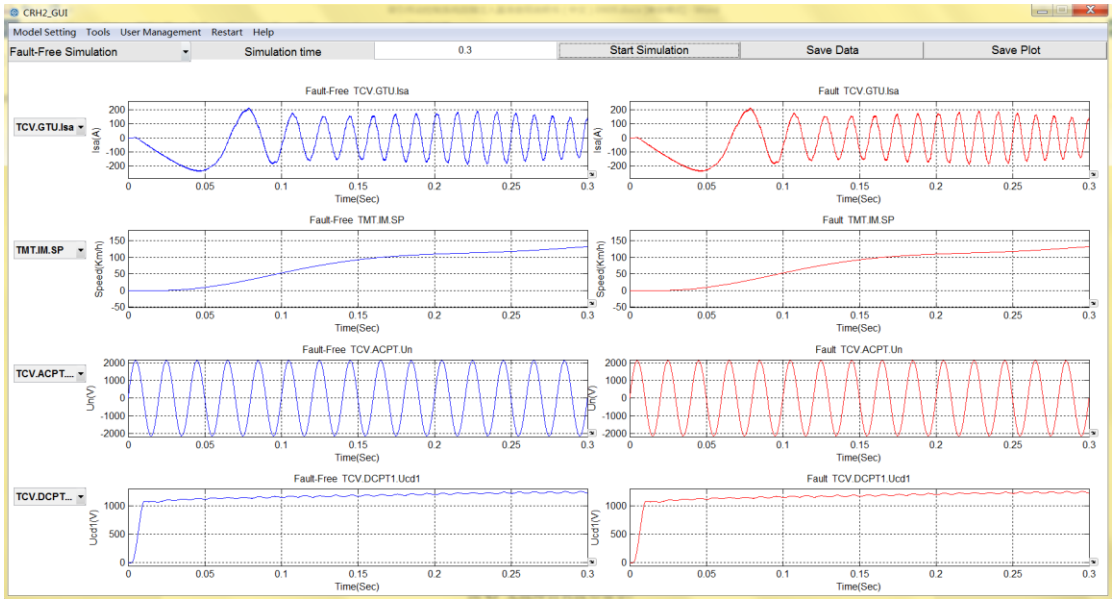
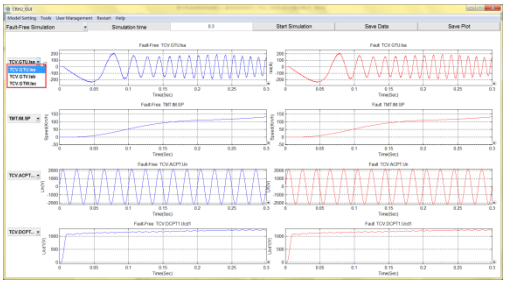
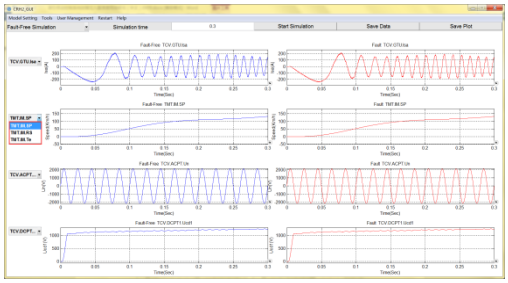


Fig. 47 Waveforms of fault-free simulation

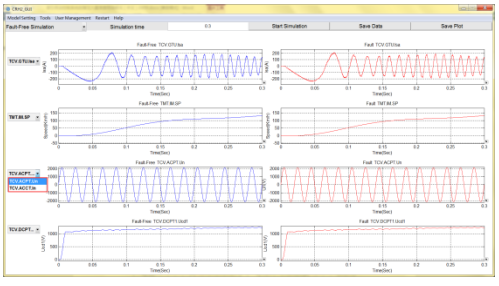
⑤By means of the drop-down menu in the waveform's left side, observation point can observe waveform of the different parameters, as shown in the red box in Fig.48 (a), (b), (c), (d).



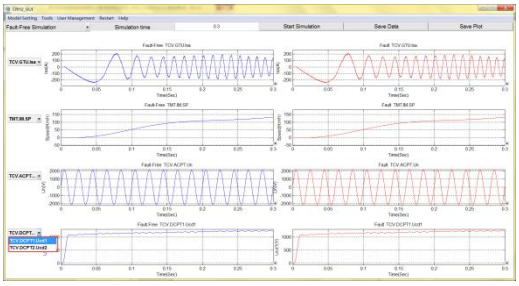
(a)



(b)



(c)



(d)

Fig. 48 Observation point selection

⑥Save the simulation data as shown in Fig. 49.

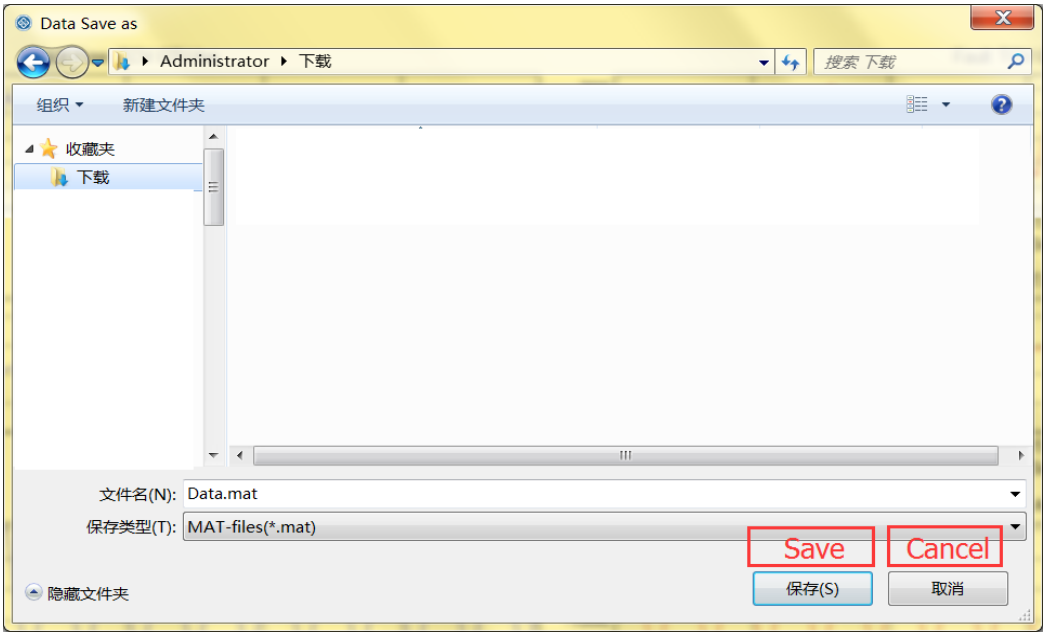


Fig. 49 Save simulation data

⑦Save the simulation waveforms as shown in Fig. 50.

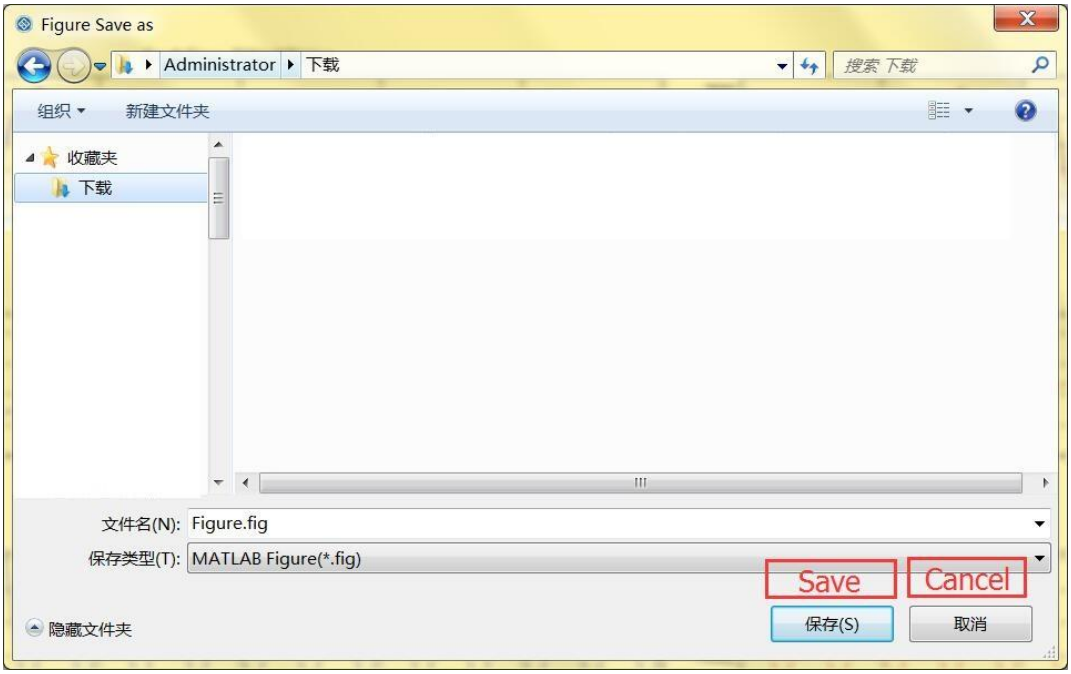


Fig. 50 Save plot

⑧After the simulation, the user can find the corresponding file under the corresponding folder to view the simulation results.

3.7.2 Simulation Example2：Sensor fault simulation

①Select the ‘Sensor Fault Injection Setting’, then will pop-up sensor fault injection location interface as shown in Fig. 51.

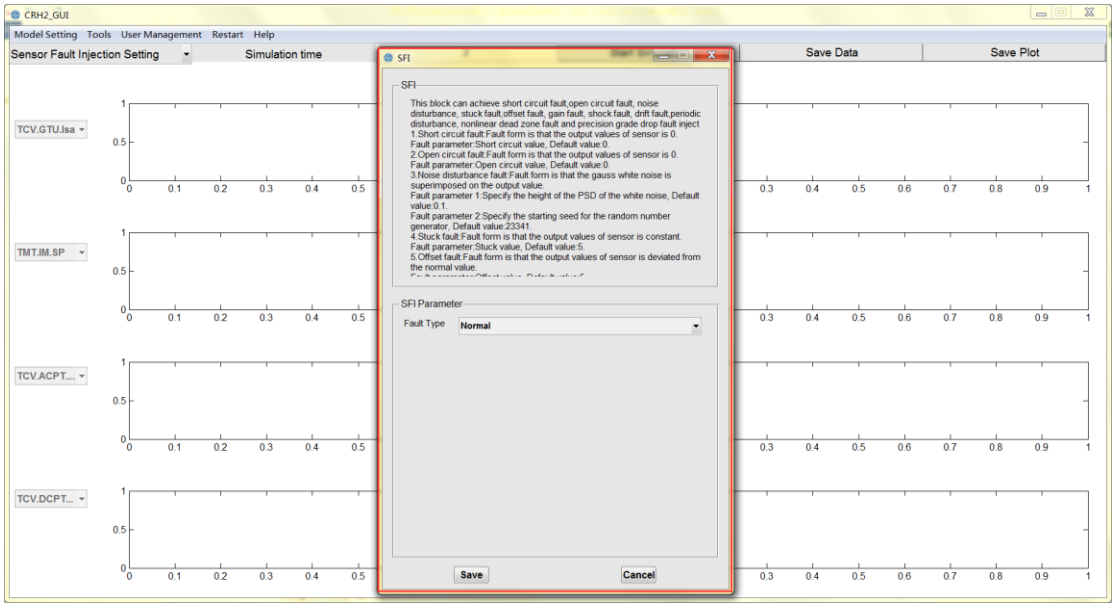


Fig. 51 Sensor fault injection setting

③Select the sensor fault type as shown in Fig. 52.

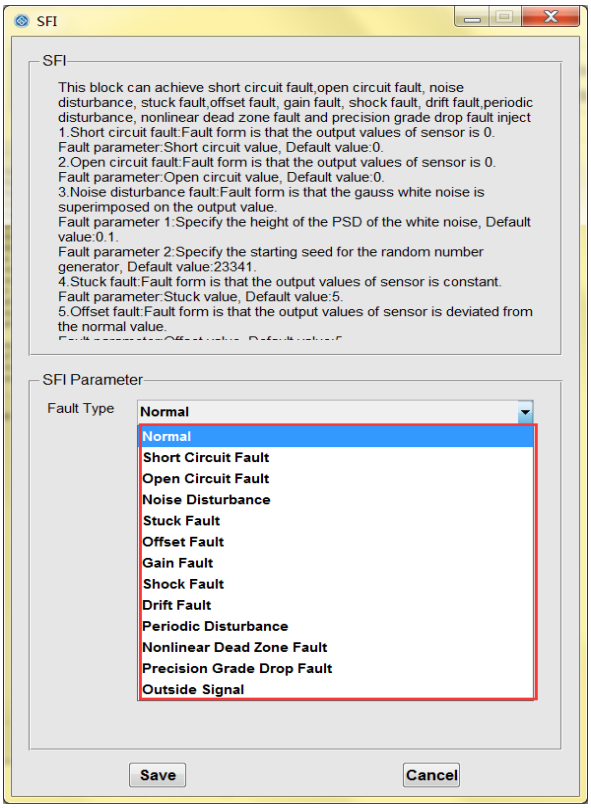


Fig. 52 Sensor fault type selection

④Select the short circuit fault (Short Circuit Fault), set the fault injection time to 1s, the fault injection location is 'U-phase in the three-phase current of the inverter', click on 'Save' and wait a minute, as shown in Fig. 53.

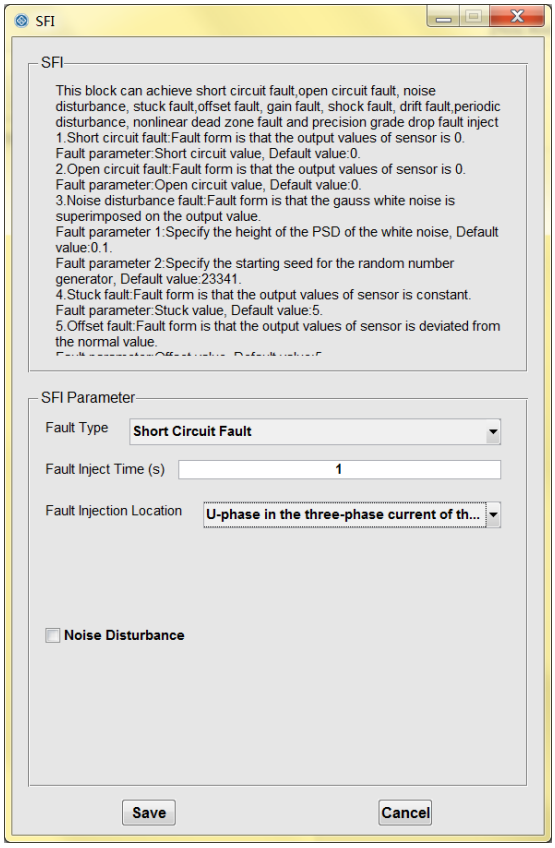


Fig. 53 Fault parameter setting

⑤Set the simulation time, the simulation duration is 2 seconds, as shown in Fig. 54.

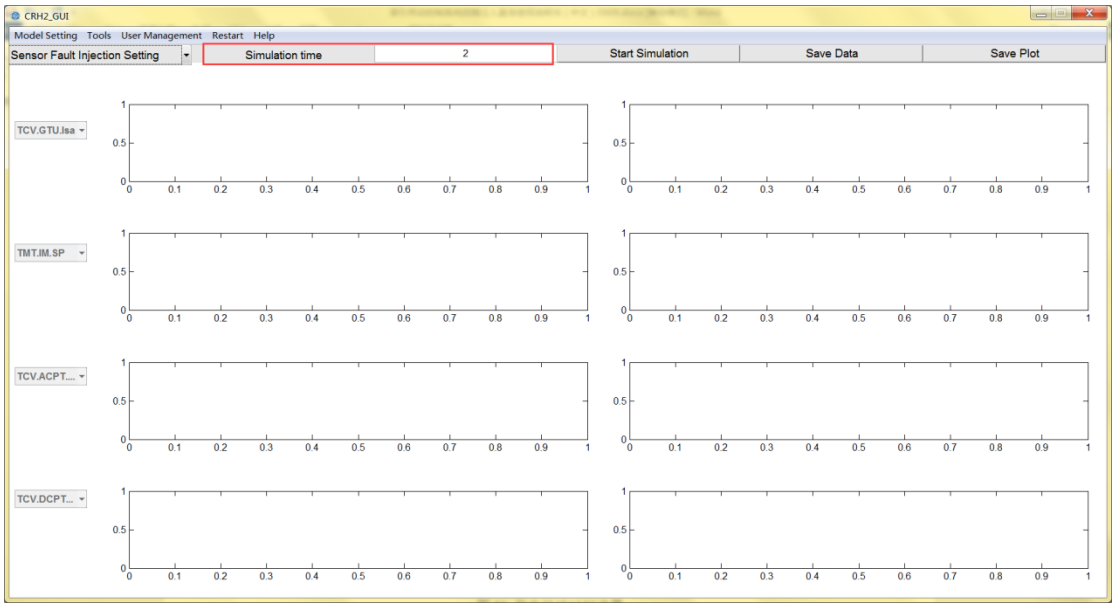


Fig. 54 Simulation time setting

⑥Click the ‘Start Simulation’ button to start the simulation, as shown in Fig. 55.

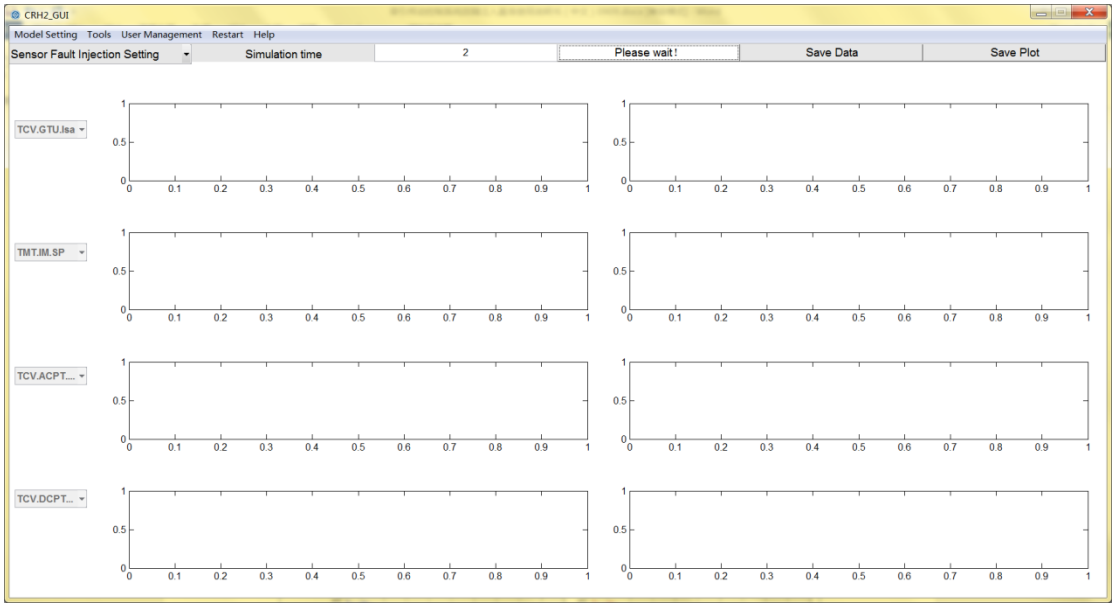


Fig. 55 Being simulation

⑦Output simulation waveform, the left is the normal waveform, the right is the fault waveform, as shown in Fig. 56.

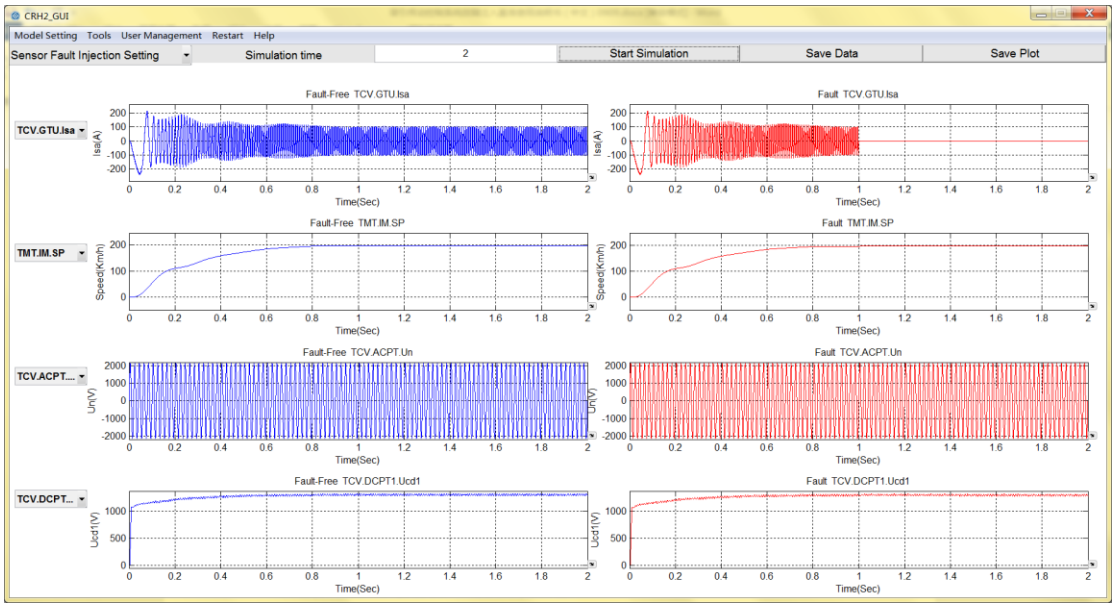


Fig. 56 Simulation waveform

⑧Select the different parameter waveforms to observe by observing point drop-down menu, as shown in Fig. 48.

⑨Click ‘save data’, save the simulation data, and custom save location, as shown in Fig. 49.

⑩Click ‘save plot’, save the simulation waveform, custom save location, as shown in Fig. 50.

⑪After the simulation, the user can find the corresponding folder to view the simulation results.

The steps for other simulation are similar, please refer to the operation of this example.