Application Note APN0036
Smart NE Solenoid Driver D5293S and
Smart ND and F&G Solenoid Driver D5294S

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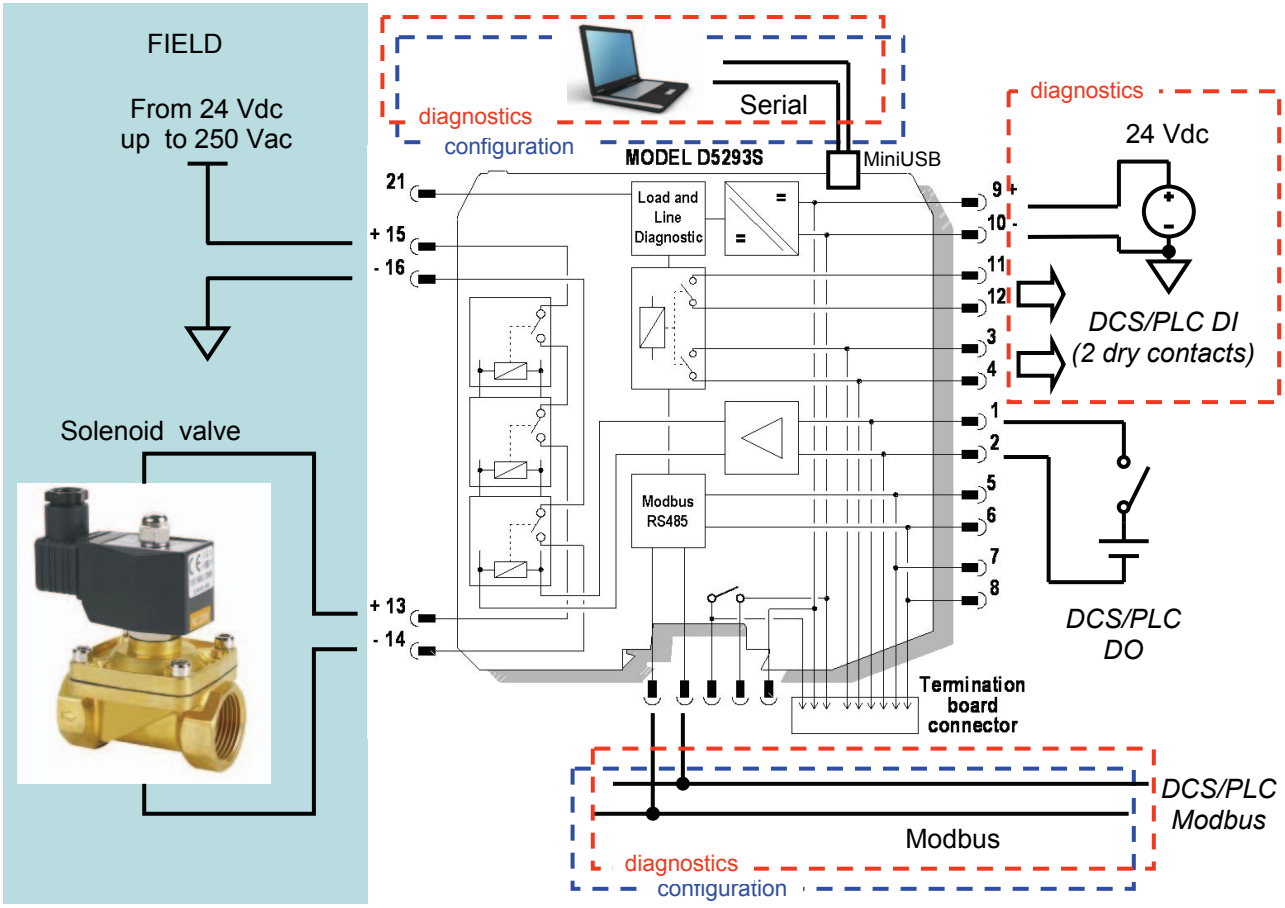
Presentation
The two relay modules D5293S and D5294S provide solenoid valve driving capabilities together with unique diagnostic functions, which include:

- Load voltage monitoring
- Load current monitoring
- Load resistance monitoring
- Earth leakage monitoring
- Internal relay coil short circuit monitoring

The D5293S module can be applied to Normally Energized (NE) loads, whereas the D5294S can be applied to Normally De-Energized (ND) loads, Fire & Gas applications, and to High Availability NE loads.
Load voltage, current, resistance and earth leakage nominal values along with their acceptable working ranges can be tailored via software to the specific application. In this way the solenoid monitoring is not limited to open and short circuit, but can detect even solenoid intra-winding partial short circuits, single coil open circuit in double-coil redundant applications, load voltage reduction or earth leakage increase.
The following Notes show some applications: typical settings and a few fault conditions are provided.

1 Smart NE Solenoid Driver D5293S: Typical Application



The figure shows a typical application of a D5293S. On the field side, a Normally Energized (NE) solenoid valve is connected to the barrier, together with its power supply (from 24 Vdc up to 250 Vac). The three normally open (NO) contacts in series are activated by a DCS/PLC DO.

The barrier can be configured:

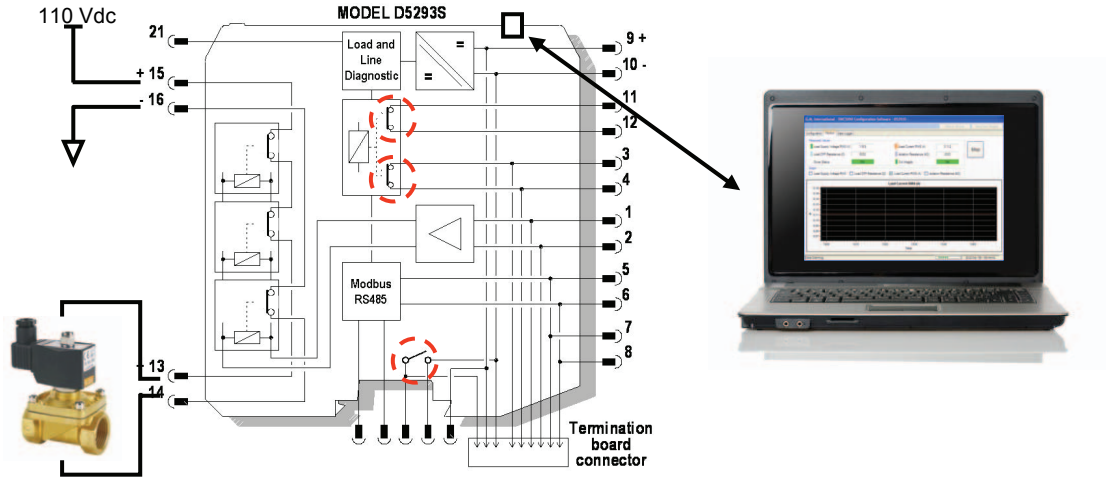
1. with a PC through a serial point-to-point connection or
2. through Modbus (multi-drop connection).

The diagnostic, supplied at 24 Vdc, provides real time information about the field in the following ways:

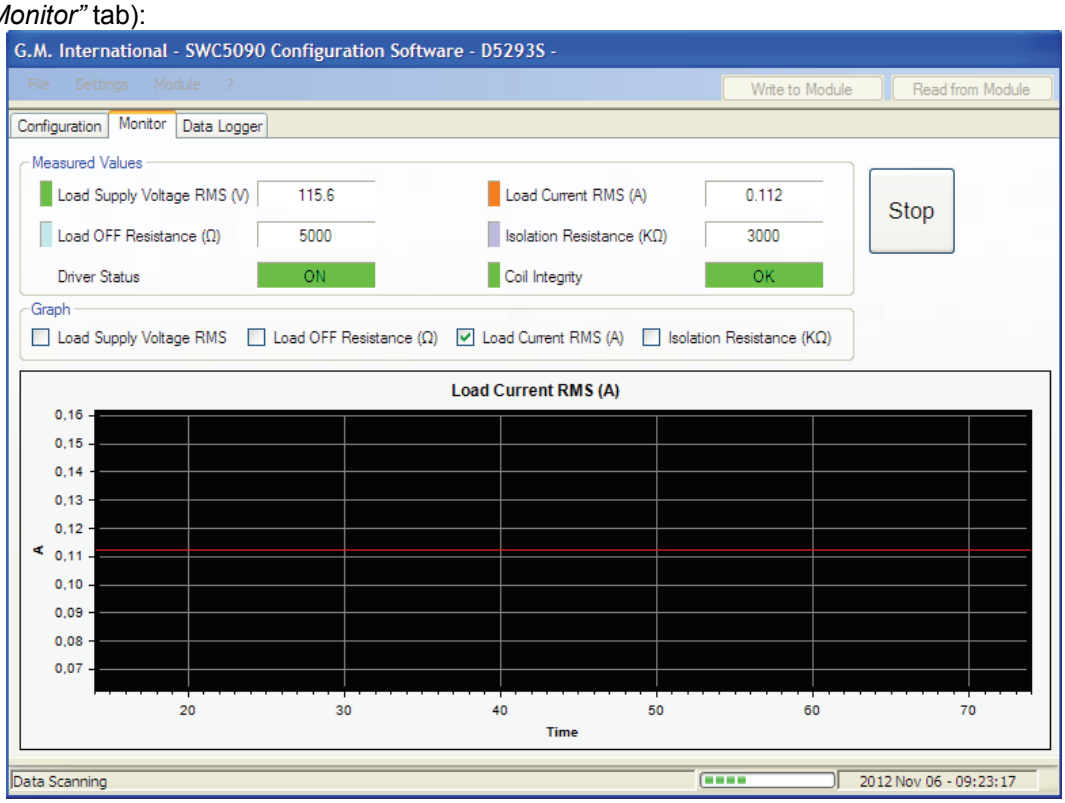
1. a fault red LED,
2. two dry contacts,
3. a bus fault contact,
4. on Modbus,
5. at the Serial interface.

1.1 Use of the diagnostics on D5293S: normal operating conditions

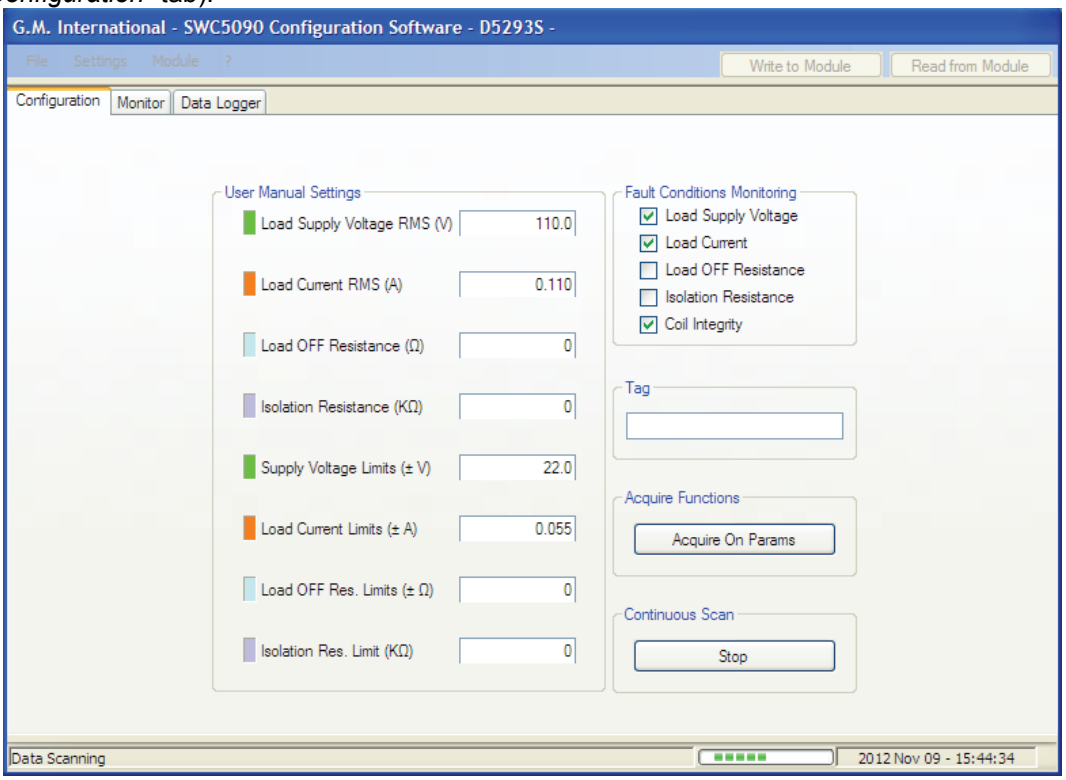
Relay module setup:



Configurator (*"Monitor"* tab):



Configurator (*"Configuration"* tab):



Suppose to connect the D5293S module to a 110 Vdc supplying a NE solenoid valve, with around 1 kOhm resistance. After connecting a PC via serial line (through the miniUSB port), the configuration/diagnostic interface would appear as in the pictures above.
By pressing the "*Start"* button in the *"Monitor"* tab, the *"Measured Values"* frame collects the data acquired from the field. In this example, the diagnostic reads 115.6 Vdc applied to the solenoid and 0.112 A flowing through it. Moreover, the relays are active (*Driver Status* is ON). *Line OFF Resistance* and *Isolation Fault* are not measured when the load is active, hence the saturation values are displayed (5000 Ohm and 3000 kOhm respectively).
The *"User Manual Settings"* indicate the acceptable ranges of operability for the considered valve: voltage supply = 110 V ± 22 V; load current = 0.110 A ± 0.055 A. Nominal values may also be acquired from the field through the "*Acquire On Params"* button in the *"Acquire Functions"* frame. This button is available only during field data scanning.
However, acceptable limits must be introduced by the user.

The *"Fault Conditions Monitoring"* frame specifies which conditions should affect the cumulative fault.
In the example above, the fault is signalled if at least one of the following situations occurs:

1. the supply voltage exceeds 132 Vdc or falls below 88 Vdc;
2. the load current is higher than 0.165 A or lower than 0.055 A;
3. an internal relay coil short is reported.

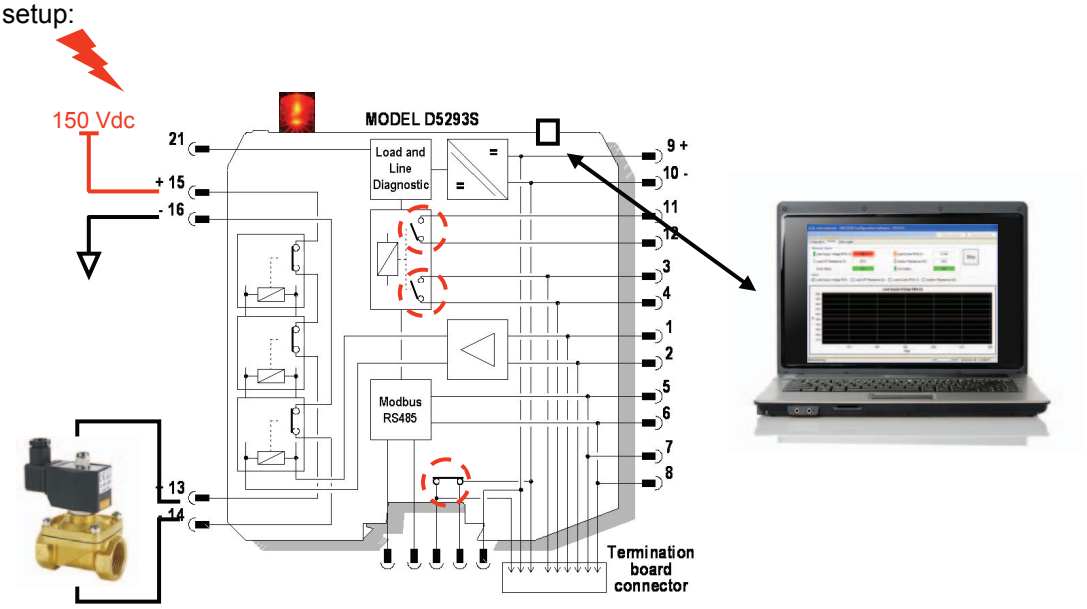
Remember to press the *"Write to Module"* button in order to upload the configuration onto the relay module. The button is available only when field data scanning is off.

In the example above, since none of these conditions holds, the fault is not asserted.
Hence:

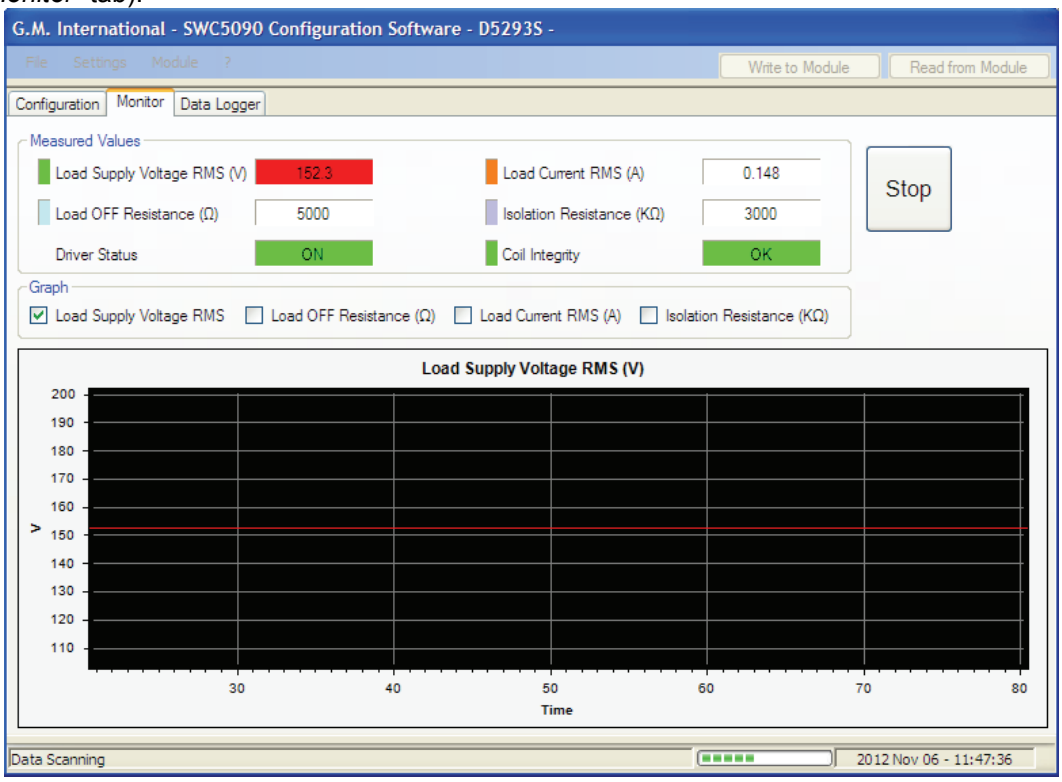
1. the two fault dry contacts are closed,
2. the bus fault contact is open,
3. the fault LED is off.

1.2 Use of the diagnostics on D5293S: supply fault

Relay module setup:



Configurator (*"Monitor"* tab):



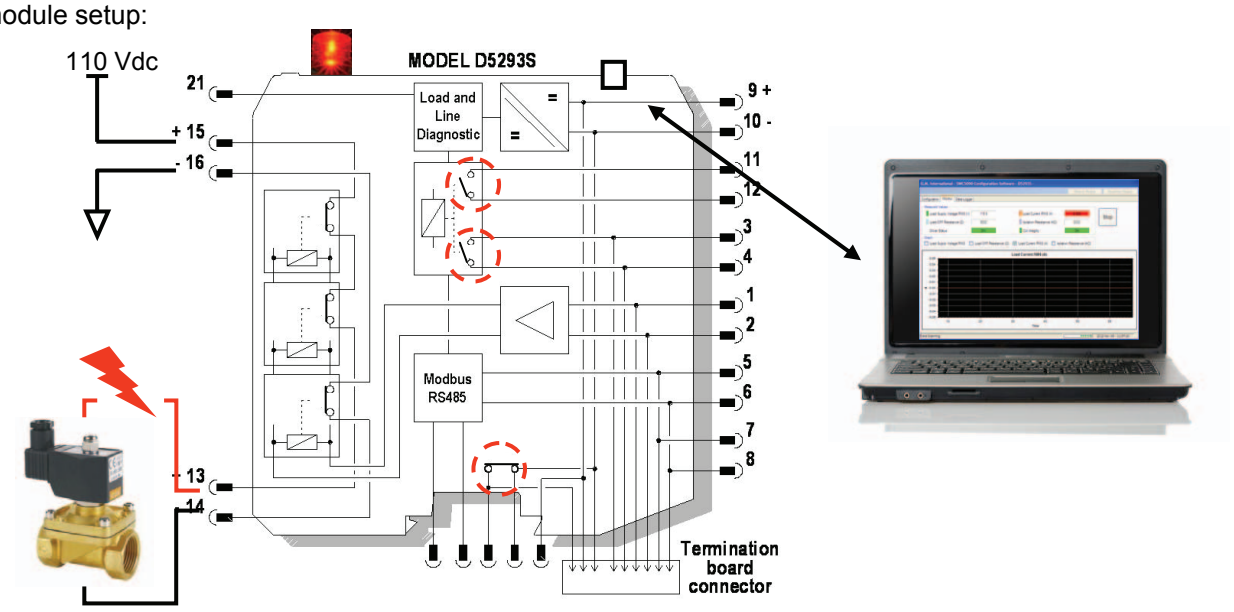
Under the same conditions as before, suppose that a load supply overvoltage occurs.
Since the measured supply voltage of 152.3 Vdc exceeds the maximum acceptable value of 110 V + 22 V = 132 Vdc, the fault is signalled.
Hence:

1. the two fault dry contacts open,
2. the bus fault contact closes,
3. the red fault LED lights up.

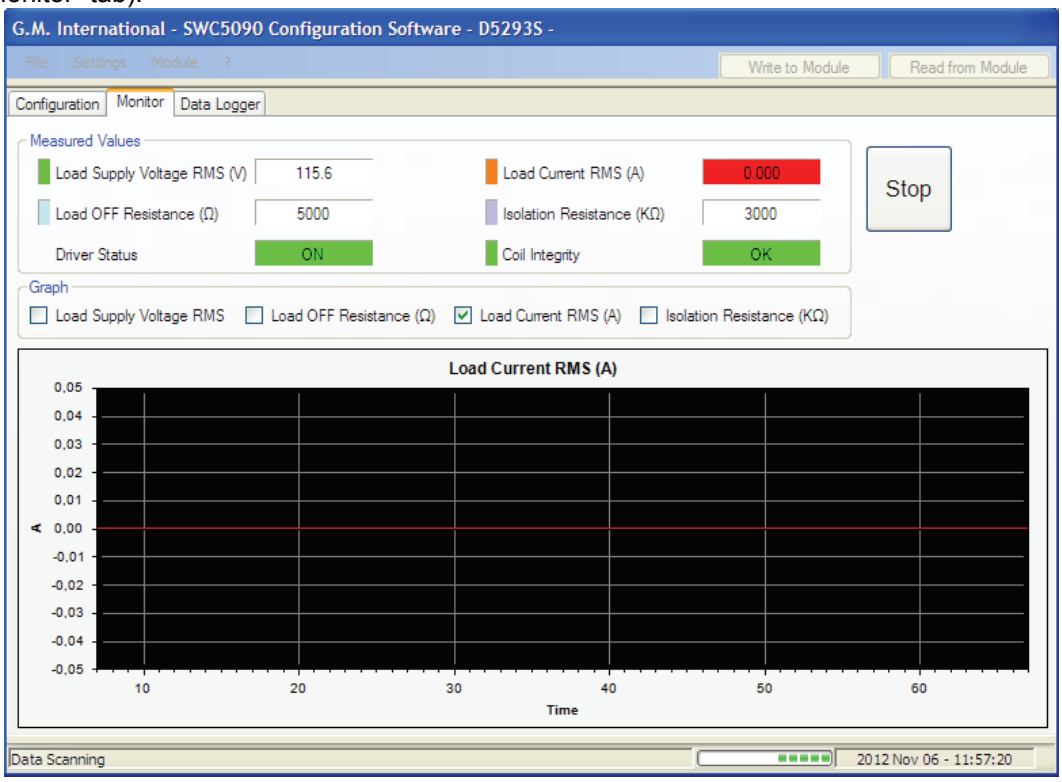
Additionally, the D5293S interface indicates which conditions are responsible for the fault activation: the line voltage becomes red in the *"Measured values"* frame in the *"Monitor"* tab. Note that the supply overvoltage also causes a current increase, but this keeps inside the acceptable range 0.110 A + 0.055 A = 0.165 A.

1.3 Use of the diagnostics on D5293S: load open circuit

Relay module setup:



Configurator ("Monitor" tab):



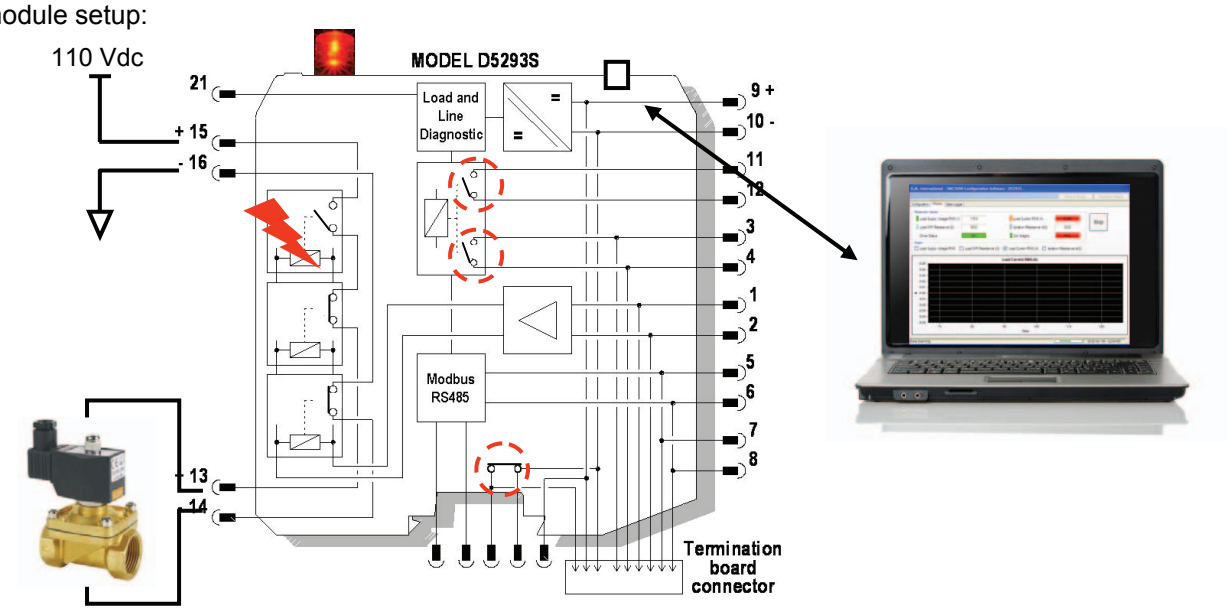
Under the same operating conditions as before, suppose that the load opens.
Since the measured load current of 0 A is well below the minimum acceptable value of 0.110 A - 0.055 A = 0.055 A, the fault is signalled.
Hence:

4. the two fault dry contacts open,
5. the bus fault contact closes,
6. the red fault LED lights up.

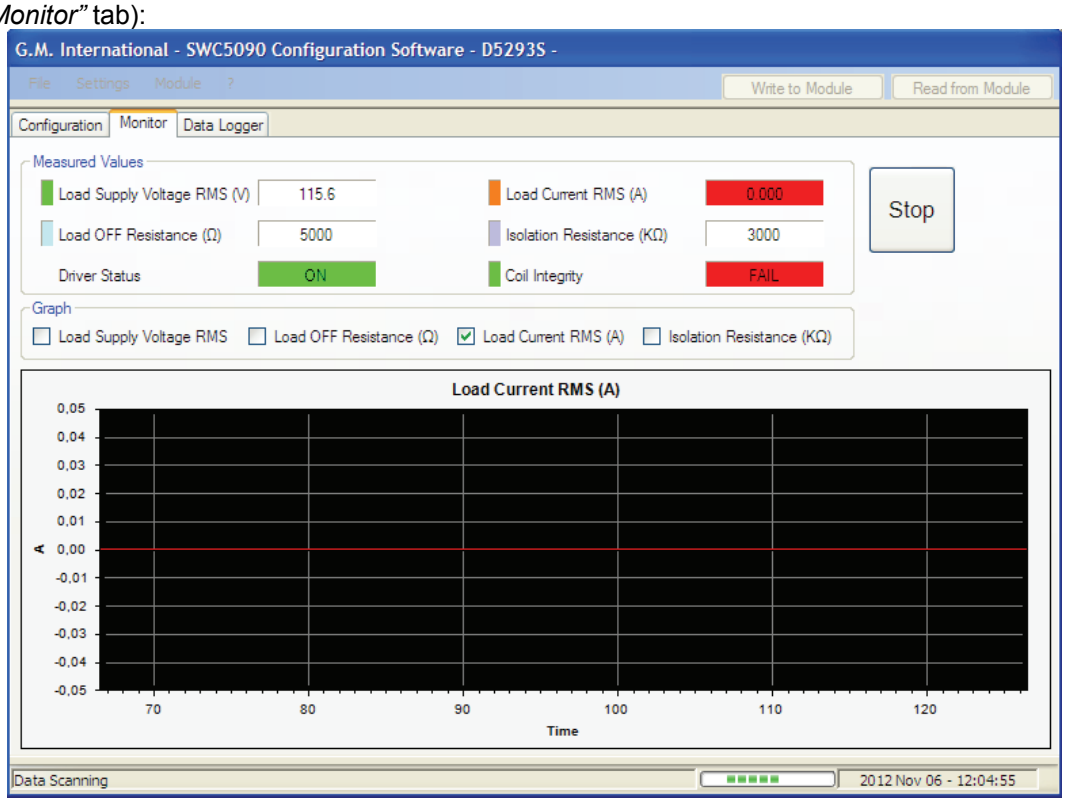
Additionally, the D5293S interface indicates which conditions are responsible for the fault activation: the load current becomes red in the *"Measured values"* frame.

1.4 Use of the diagnostics on D5293S: internal relay coil short circuit

Relay module setup:



Configurator (*"Monitor"* tab):

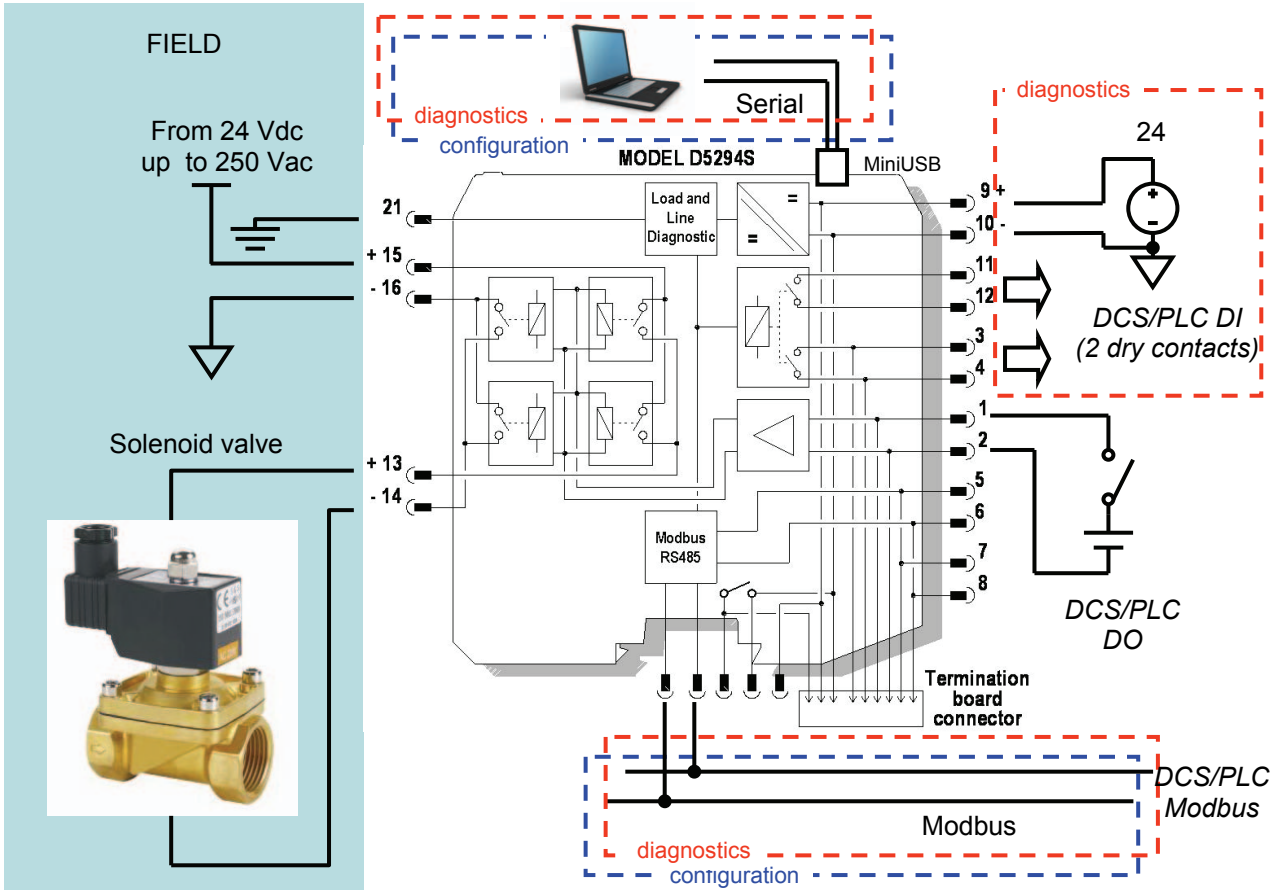


Under the same operating conditions as before, suppose that one coil of the three series relays of the D5293S interface goes to short-circuit. As a consequence, the load current becomes zero.
Since the reported *Coil Integrity* is FAIL and the load current drops below 0.110 A – 0.055 A = 0.055 A, the fault is signalled.
Hence:

7. the two fault dry contacts open,
8. the bus fault contact closes,
9. the red fault LED switches on.

Additionally, the D5293S interface indicates which conditions are responsible for the fault activation: the *Coil Integrity* and the *Load Current* become red in the *"Measured values"* frame in the *"Monitor"* tab. The reported *Coil Integrity* failure allows the user to distinguish between a load open circuit (see previous example) and an internal relay coil short.

2 Smart ND and Fire&Gas Solenoid Driver D5294S: Typical Application



The figure shows a typical application of a D5294S. On the field side, a solenoid valve for Fire & Gas (F&G) is connected to the module, together with its power supply (from 24 Vdc up to 250 Vac). The 2x2 normally open (NO) relays are activated by a DCS/PLC DO.

The barrier can be configured:

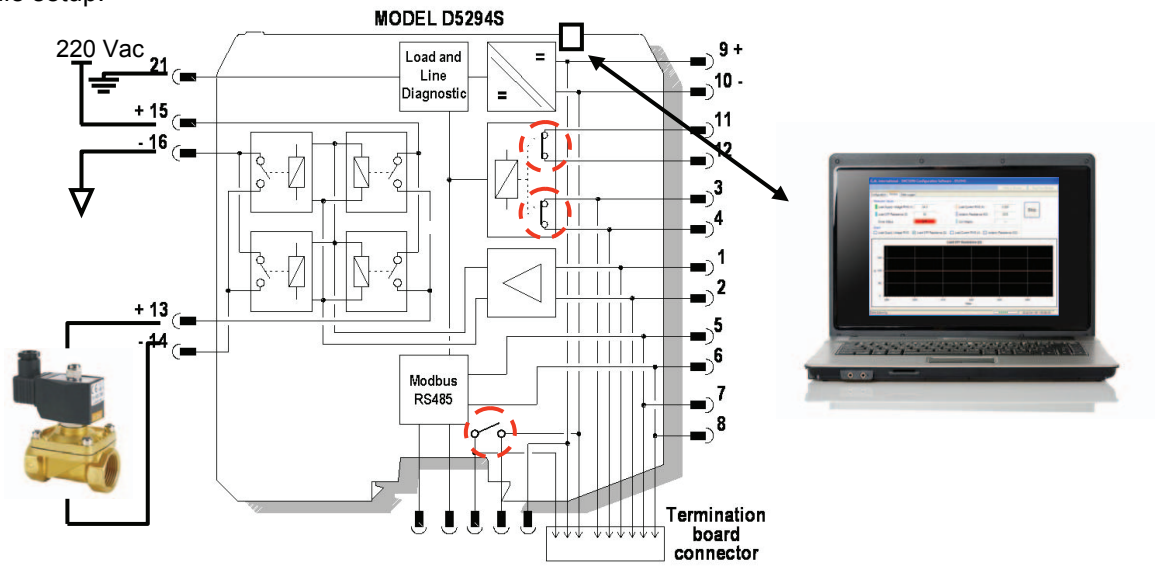
1. with a PC through a serial point-to-point connection or
2. through Modbus (multi-drop connection).

The diagnostic, supplied at 24 Vdc, provides real time information about the field in the following ways:

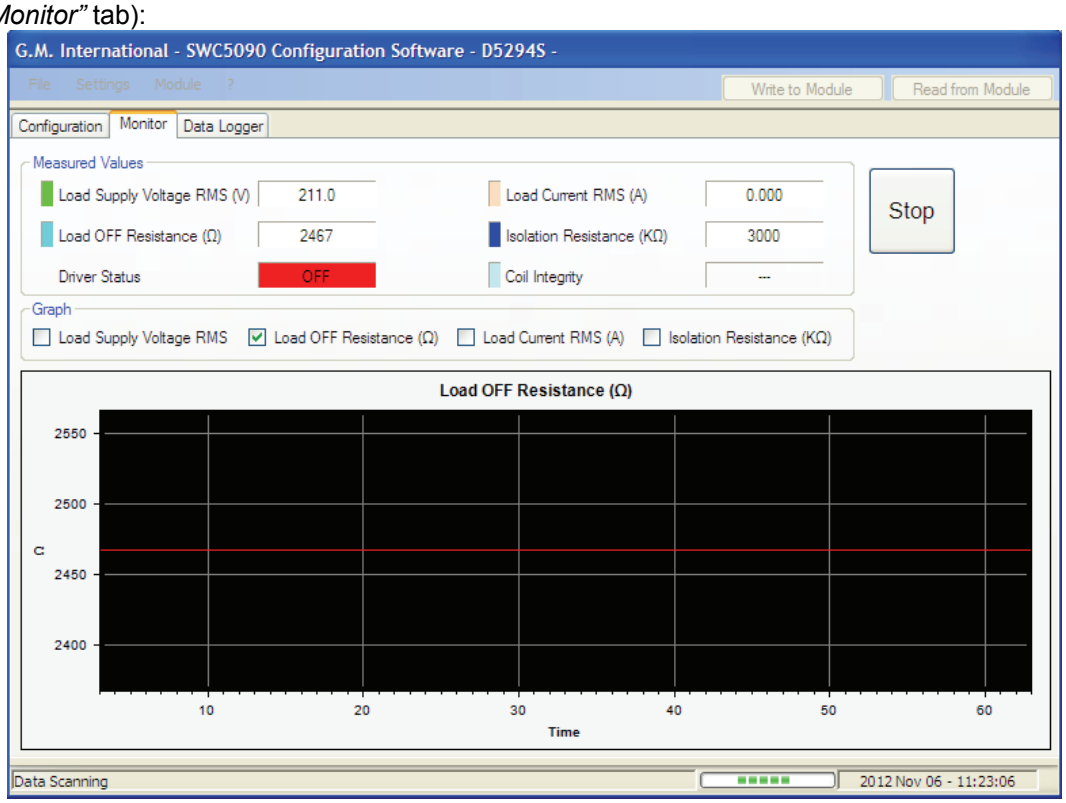
1. a fault red LED,
2. two dry contacts,
3. a bus fault contact,
4. on Modbus,
5. at the Serial interface.

2.1 Use of the diagnostics on D5294S: normal operating conditions

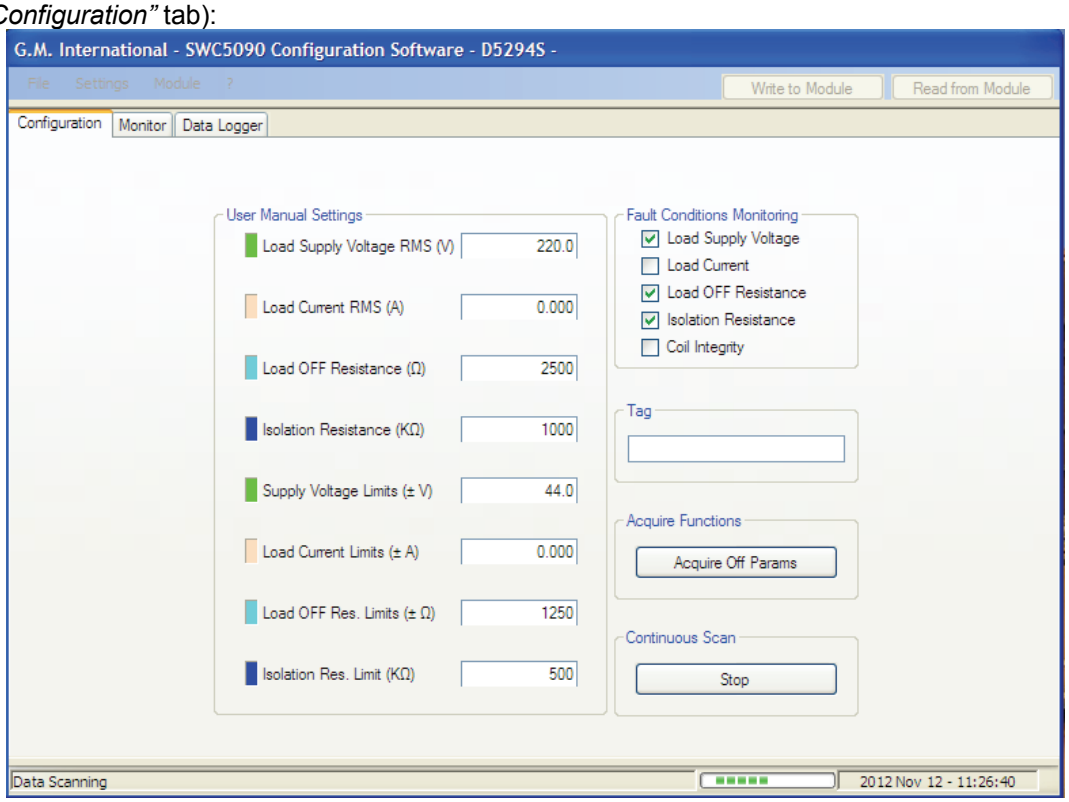
Relay module setup:



Configurator (*"Monitor"* tab):



Configurator (*"Configuration"* tab):



Suppose to connect the D5294S module to a 220 Vac that will supply a solenoid valve for F&G applications, with around 2.5 kOhm resistance. After connecting a PC via serial line (through the miniUSB port), the configuration/diagnostic interface would appear as in the picture above.
By pressing the *Start* button in the *"Monitor"* tab, the *"Measured Values"* frame collects the data acquired from the field. In this example, the diagnostic reads 211.0 Vac, which will be applied to the valve at the activation, the solenoid resistance is 2467 Ohm and the earth leakage is above the saturation value (3000 kOhm = 3 MOhm).
Moreover, the relays are off (*Driver Status* is OFF).
The *"User Manual Settings"* in the *"Configuration"* tab indicate the acceptable ranges of operability for the considered valve: voltage supply = 220 V ± 44 V; valve solenoid resistance = 2500 Ohm ± 1250 Ohm, resistance towards earth = 1000 kOhm – 500 kOhm.
Nominal values may be acquired from the field through the *"Acquire Off Params"* button in the *"Acquire Functions"* frame. This button is available only during field data scanning. However, acceptable limits must be introduced by the user.

The *"Fault Conditions"* frame specifies which conditions should affect the cumulative fault:
In the example above, the fault is signalled if at least one of the following situations occurs:

1. the supply voltage exceeds 264 Vdc or falls below 176 Vdc;
2. the valve solenoid resistance is higher than 3750 Ohm or lower than 1250 Ohm;
3. the earth leakage resistance drops below 500 kOhm.

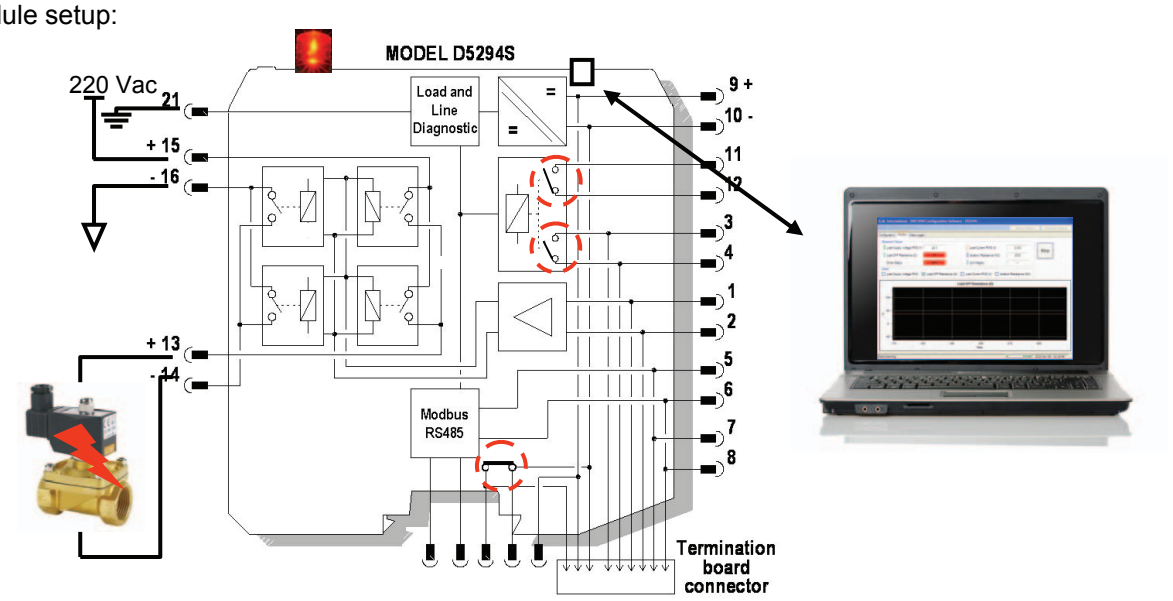
Remember to press the *"Write to Module"* button in order to upload the configuration onto the relay module. The button is available only when field data scanning is off.

In the example above, since none of these conditions holds, the fault is not asserted.
Hence:

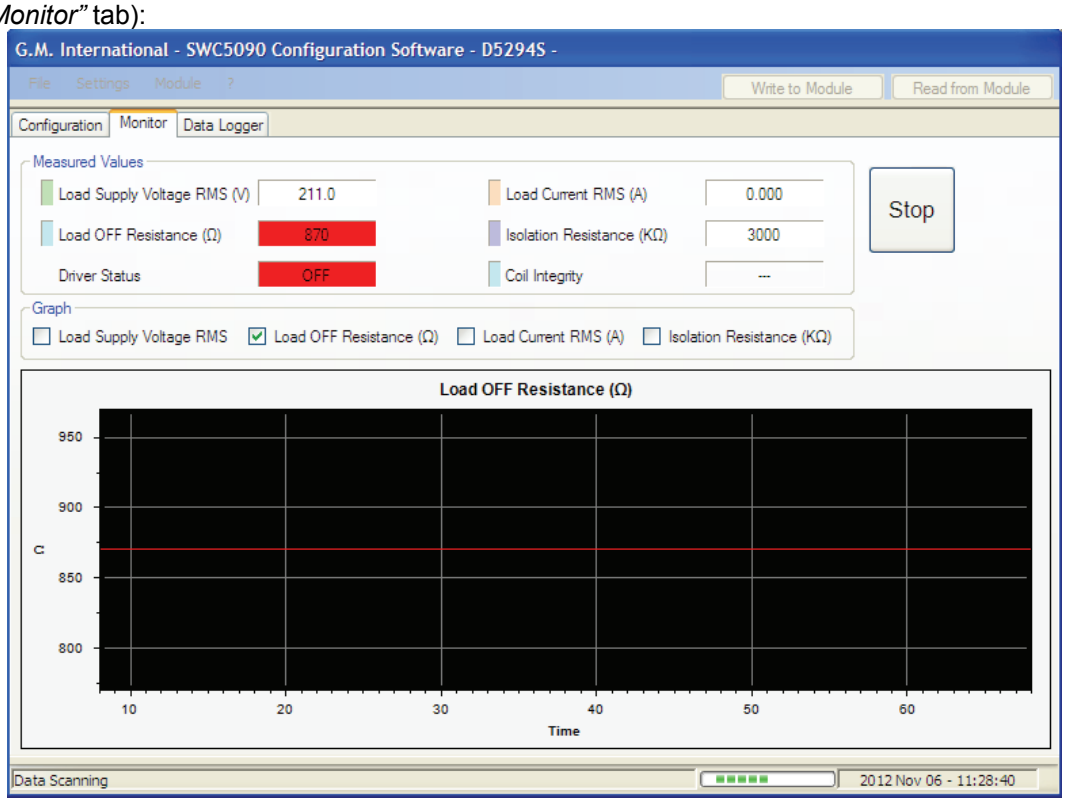
1. the two fault dry contacts are closed,
2. the bus fault contact is open,
3. the fault LED is off.

2.2 Use of the diagnostics on D5294S: intra-winding short circuit

Relay module setup:



Configurator (*"Monitor"* tab):



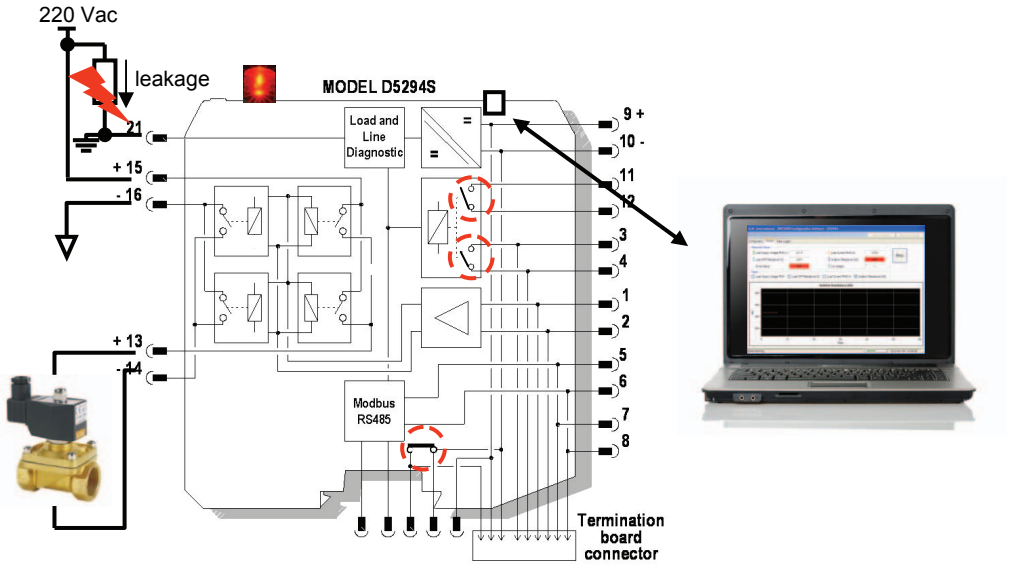
Under the same conditions as before, suppose that the valve is affected by a partial short circuit of the solenoid winding, hence compromising its capability of activation on demand.
Since the measured *Load OFF Resistance* of 870 Ohm is below the acceptable value of 2500 Ohm - 1250 Ohm = 1250 Ohm, the fault is signalled.
Hence:

10. the two fault dry contacts open,
11. the bus fault contact closes,
12. the red fault LED lights up.

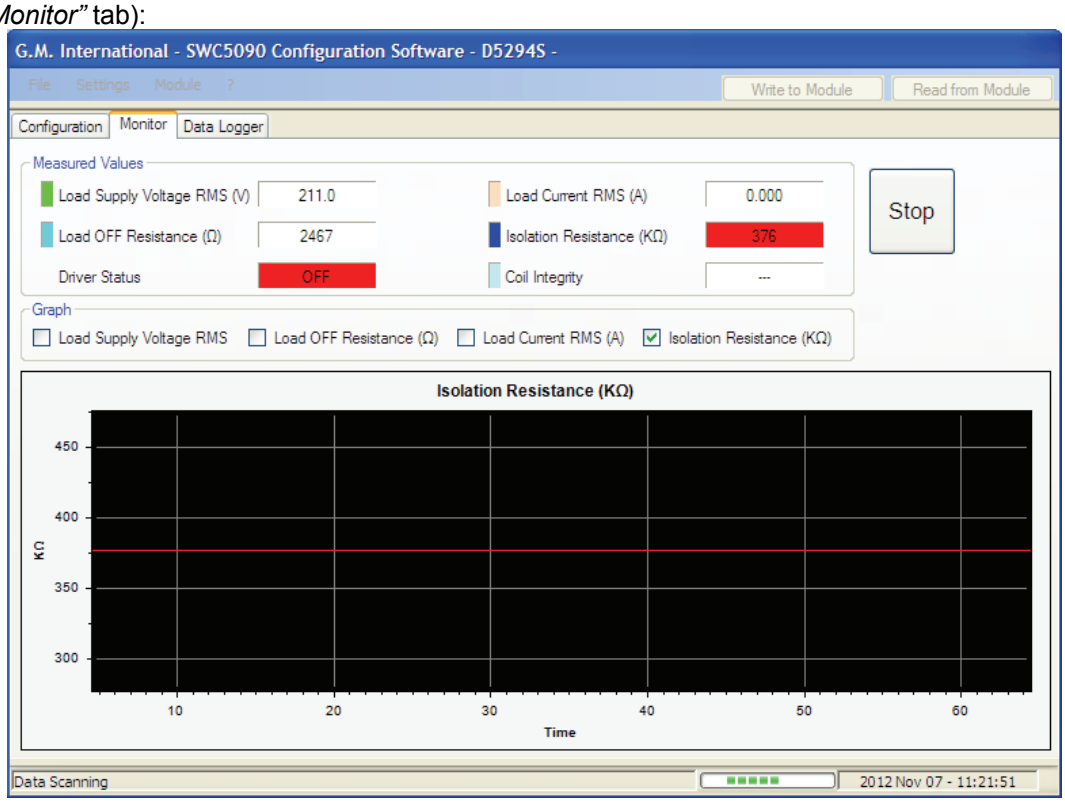
Additionally, the D5294S interface indicates which conditions are responsible for the fault activation: the *Load OFF Resistance* becomes red in the *"Measured Values"* frame in the *"Monitor"* tab.

2.3 Use of the diagnostics on D5294S: earth leakage

Relay module setup:



Configurator (*"Monitor"* tab):



Under the same conditions as before, suppose that the earth isolation degrades.
Since the measured *Isolation Resistance* of 376 kOhm is below the acceptable value of 1 MOhm - 500 kOhm = 500 kOhm, the fault is signalled.
Hence:

13. the two fault dry contacts open,
14. the bus fault contact closes,
15. the red fault LED lights up.

Additionally, the D5294S interface indicates which conditions are responsible for the fault activation: the *Isolation Resistance* becomes red in the *"Measured values"* frame in the *"Monitor"* tab.

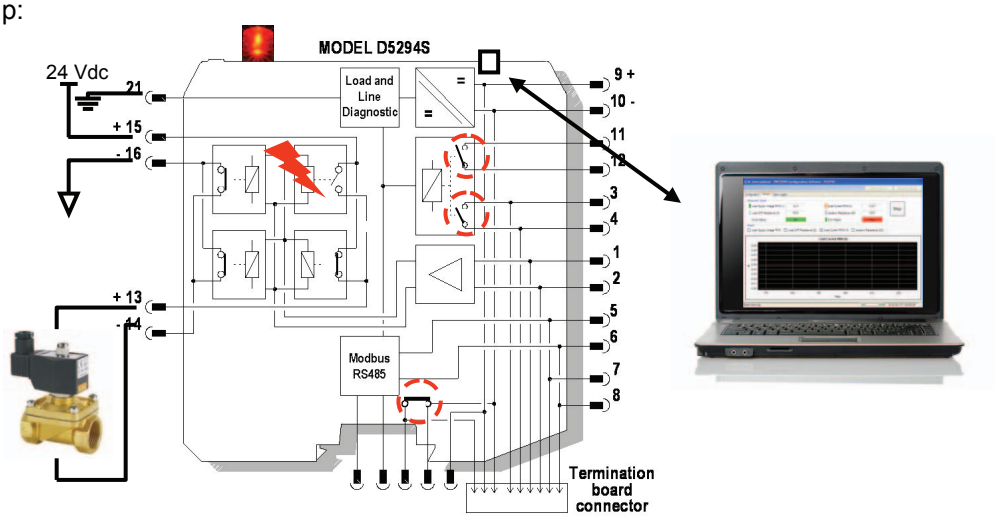
3 Special Applications

3.1 High-Availability NE loads

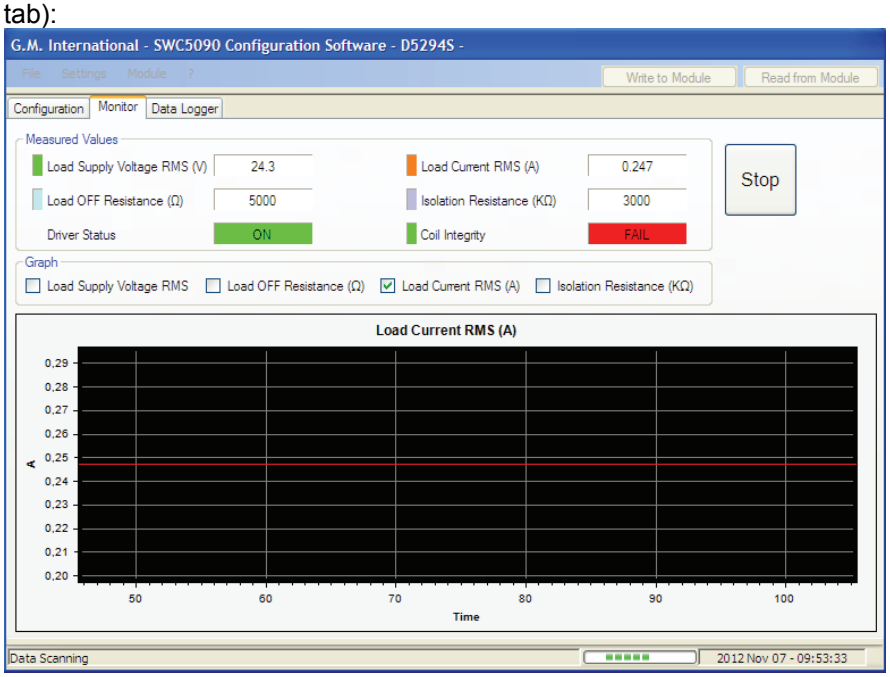
When high-availability for Normally Energized loads is required, the relay module D5294S may come into play. Its 2x2 relay redundancy provides a single NO contact with increased availability, hence decreasing the probability of false trips. This might particularly be desirable in the ESD (Emergency Shutdown) system of big plants (refineries, etc…), where a spurious fault may cause an unwanted stop. Yet, the replacement of the D5293S with the D5294S for NE loads entails a penalty: the reduction of the Tproof period for functional safety (see Frequently Asked Questions). The prevention of the D5294S from false trips becomes particularly valuable when the *"Coil Integrity Monitoring"* is activated: in case a relay hazardously opens, the load is still energized because of the 2x2 arrangement and, additionally, a predictive fault is issued.

By way of example, suppose to connect the D5294S module to a 24 Vdc supplying a NE solenoid valve, with around 100 Ohm resistance. A single relay fault would be indicated as in the pictures below:

Relay module setup:



Configurator (*"Monitor"* tab):



Note that the *Load Current* is at the nominal value, hence indicating that the load is still energized. Nevertheless, since the D5294S has lost the relay redundancy, the fault has been issued[1].

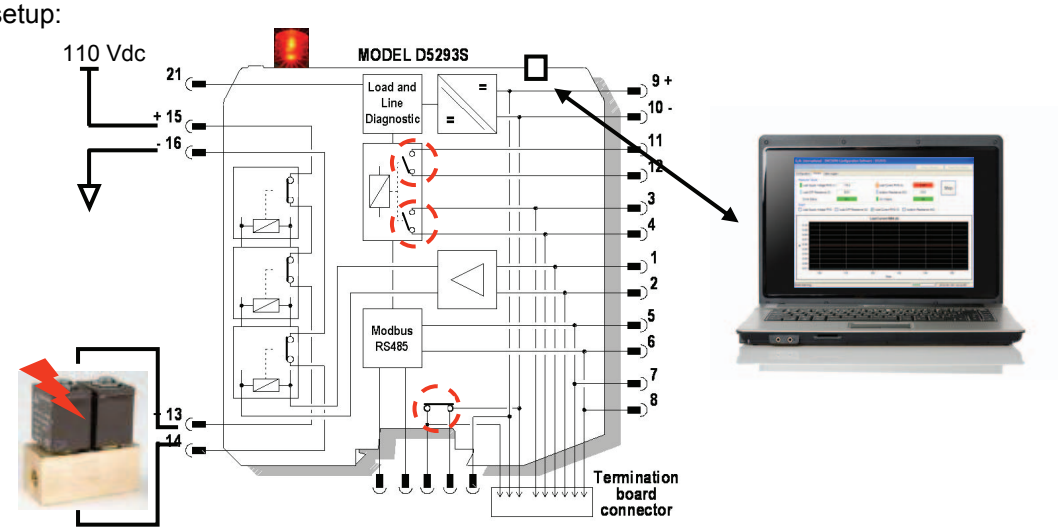
[1] Incidentally, note also that the D5294S may even support the failure of two relays without switching the load off. Yet, in order for this "lucky" case to occur, the two defective relay contacts should not belong to the same parallel branch.

3.1.1 Double-coil solenoid valves for High-Availability NE loads

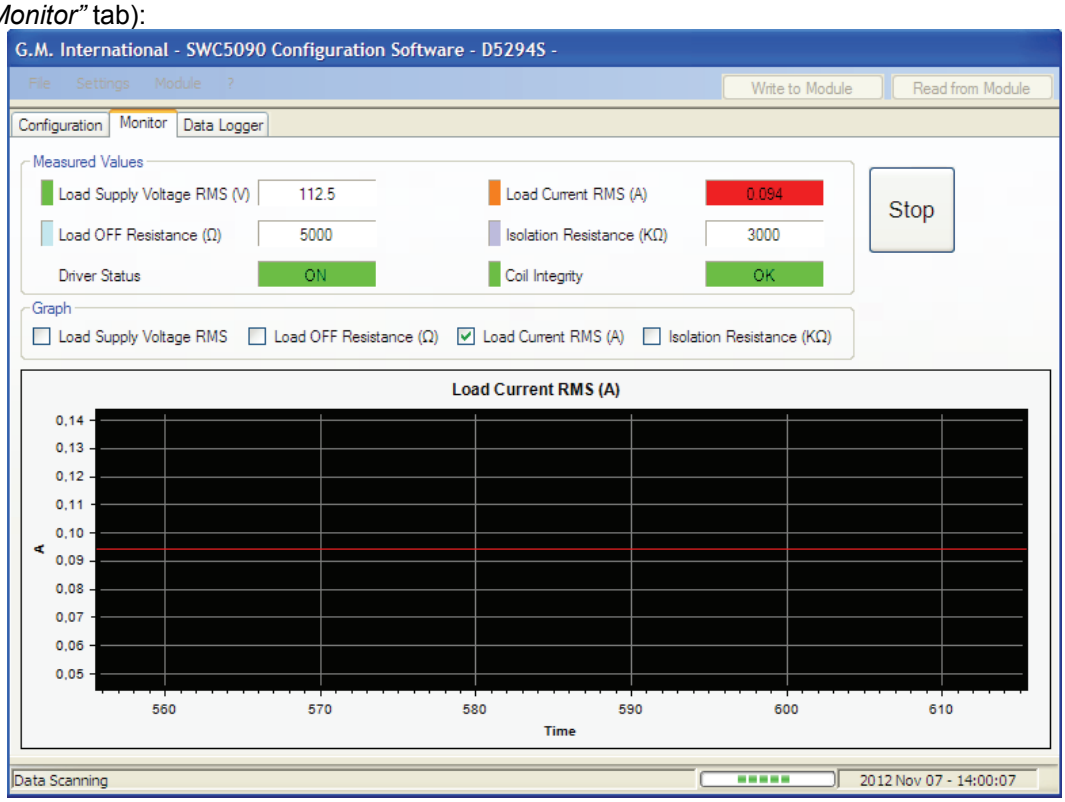
Concerning high-availability NE applications (heaters, etc…), double-coil solenoid valves may be required. Since each coil is sufficient to activate the valve, the two coils avoid false trips in case of single coil opening, hence increasing the availability. In large industrial compounds (refineries, etc…), double-coil valves are normally controlled by a single digital output driver. In this context, the D5294S is again an optimal solution, because it can detect the opening of the single valve coil, hence providing predictive diagnostics for prompt maintenance, while keeping higher availability than the D5293S module.

Suppose to have a 110 Vdc double-coil solenoid valve, with around 1200 Ohm resistance for each coil. Under regular working conditions the two coils of the valve are driven in parallel, hence the total resistance is around 600 Ohm and the load current is therefore about 0.183 A. The following pictures document the case of a single coil opening, which halves the load current.

Relay module setup:



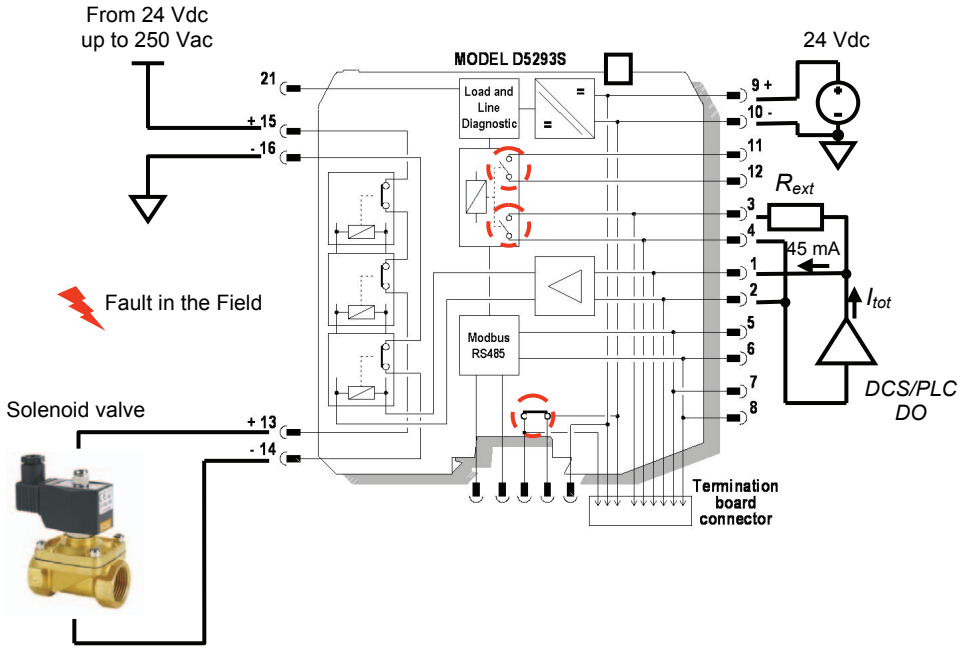
Configurator (*"Monitor"* tab):



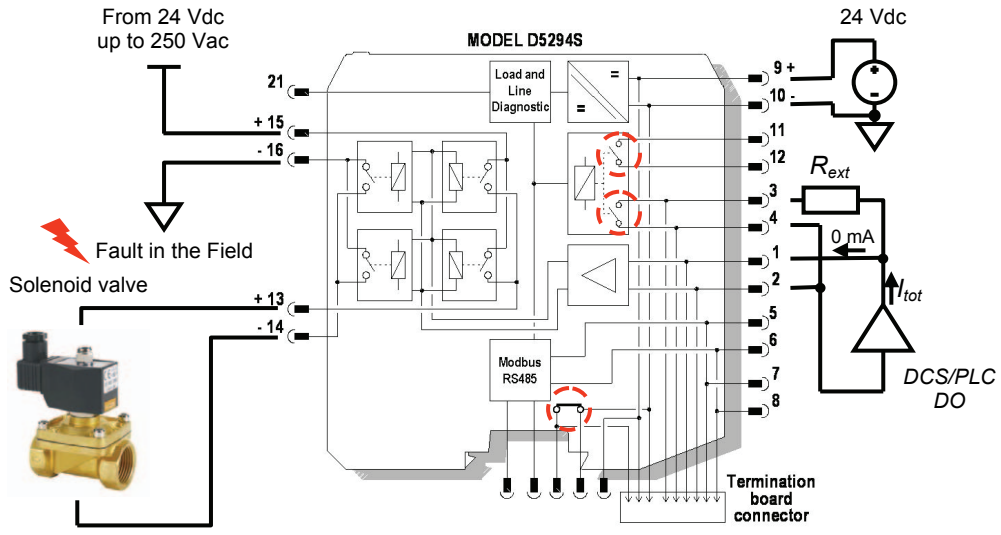
Note that, in order to detect the single coil opening, it is necessary to configure an acceptable load current range below the 50% around the nominal value.

3.2 Fault mirroring back to the PLC/DCS Digital Output

The D5293S and D5294S relay drivers indicate the fault occurrence through two dry contacts: the system would therefore need to acquire the fault information with an additional Digital Input card. Yet, some PLC/DCS systems allow the accurate measurement of the current drained by the Digital Output cards: should this be the case, the fault in the field can be reported back directly to the Digital Output, hence avoiding the Digital Input slot. Depending on the system, this feature may be available both for NE and for ND loads. The following pictures indicate the proper setup:
Relay module setup (NE loads):



The DCS/PLC Digital Output is connected to terminals 1 and 2, and, additionally, to terminals 3 and 4 through a resistance (R_{ext}). Under regular working conditions, the total current (I_{tot}) drained by the Digital Output is the sum of the relay module coil consumption (around 45 mA) plus the R_{ext} contribution, around 24 V / R_{ext}. Yet, when a fault occurs in field, the fault contact opens and the 24 V / R_{ext} contribution drops. An alarm threshold between 45 mA and 45 mA + 24 V / R_{ext} would mirror the fault in the field back to the system. R_{ext} should be sized properly, so that its power rating is not exceeded and that, at the same time, a comfortable system alarm threshold can be devised. The D5294S relay module for high-availability NE loads would work in a similar way.
Relay module setup (ND loads):



The setup is similar to NE loads. Note, however, that under regular working conditions the total current drained by the Digital Output is only the R_{ext} contribution (24 V / R_{ext}), because the relay coils are not energized. When any fault occurs in the field, the DO consumption drops almost to 0. The alarm current threshold must be fixed between 0 and 24 V / R_{ext}.

3.3 Command inversion: ND load with NE command or NE load with ND command

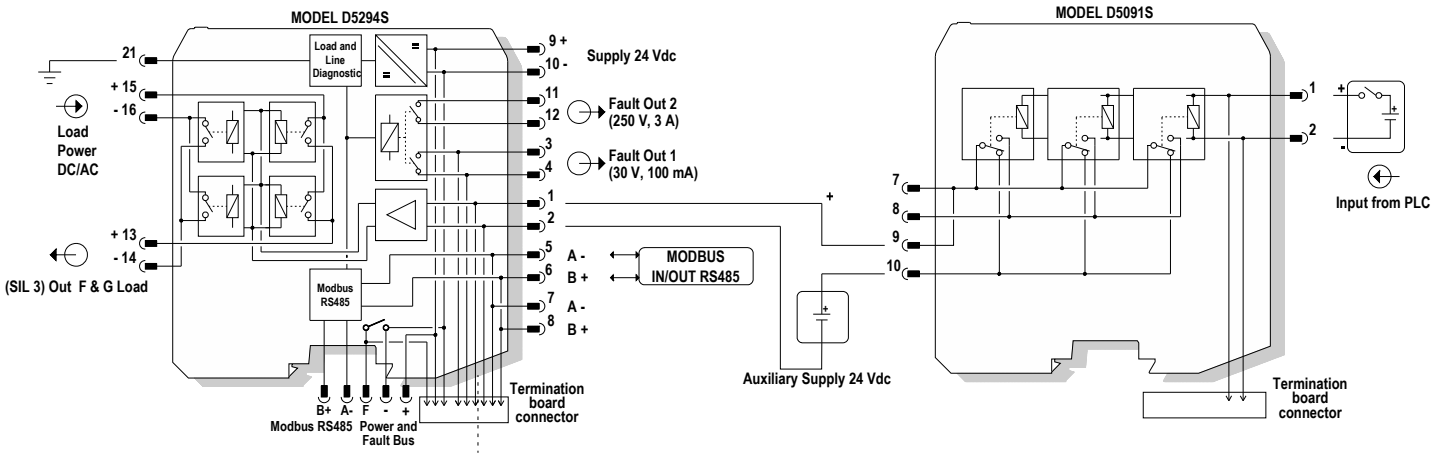
The smart relay output module D5294S reproduces the phase of the DCS/PLS output onto the load:

- When the driving signal is low (0 Vdc), the relay is de-energized and load is de-energized.
- When the driving signal is high (24 Vdc), the relay is energized, and the load is energized.

Certain applications need however that this behavior is inverted, leading to an indirect relation between the PLC output and the load status. The following sections explain how the polarity of the command signal can be inverted, when ND loads require NE commands or NE loads require ND commands, respectively.

3.3.1 Normally De-energized (ND) loads with Normally Energized (NE) commands: NE -> ND

When Normally De-energized (ND) loads require Normally Energized (NE) commands, it is necessary to interpose a D5091S module between the PLC output and the D5294S module.



The figure shows the cabling of D5091S and D5294S.
Starting from the right, the PLC output is connected to pins 1,2 of D5091S. The output signal on pins 9,10 is used to energize or de-energize the D5294S (pins 1,2).
The following table shows the behaviour of the load connected on pins 13,14 of D5294S, based on the status of the PLC output:

PLC DO	D5294S Input (pins 1,2)	D5294S Load (pins 13,14)	Condition
ON	OFF	DE-ENERGIZED	Normal State
OFF	ON	ENERGIZED	Safe State

The D5091S is therefore able to invert the functionality of the D5294S, with de-energized command to trip the safe state.
The Tproof period for functional safety is fixed by the D5294S to SIL 2 value up to 20 years, supposing D5091S + D5294S system contributes 10% of entire SIF.

3.3.2 Normally Energized (NE) loads with Normally De-energized (ND) commands: ND -> NE

When Normally Energized (NE) loads require Normally De-energized (ND) commands, it is necessary to interpose a D5090S-086 module between the PLC output and the D5294S module.

FIGURE MISSING!!!

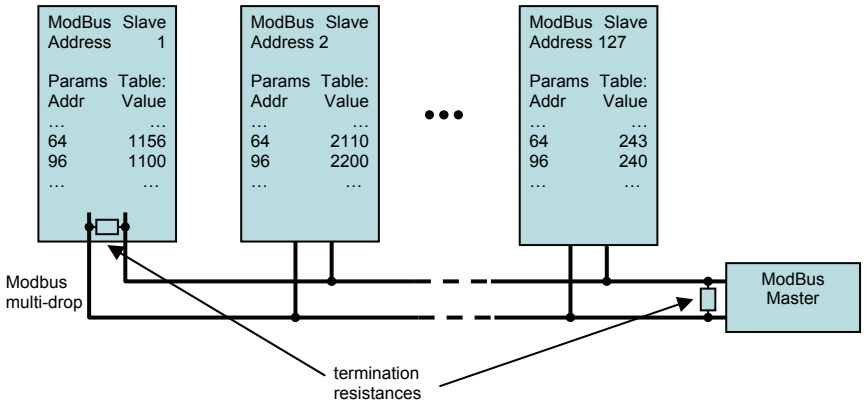
The figure shows the cabling of D5090S-086 and D5294S.
Starting from the right, the PLC output is connected to pins 1,2 of D5090S-086. The output signal on pins 11,12 is used to energize or de-energize the D5294S (pins 1,2).
The following table shows the behaviour of the load connected on pins 13,14 of D5294S, based on the status of the PLC output of D5090S-086:

D5090S-086 Input (pins 1,2)	D5294S Input (pins 1,2)	D5294S Load (pins 13,14)	Condition
OFF	ON	ENERGIZED	Normal State
ON	OFF	DE-ENERGIZED	Safe State

The D5090S-086 is therefore able to invert the functionality of the D5294S, with energized command to trip the safe state.
The Tproof period for functional safety is fixed by the D5090S-086 to SIL 3 value up to 6 years, supposing D5090S-086 + D5294S system contributes 10% of entire SIF.

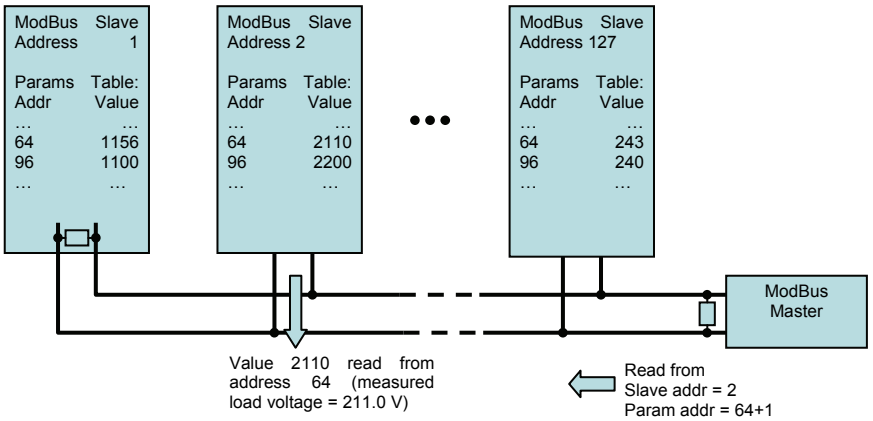
4 D5293S, D5294S: Modbus Configuration

The Relay Modules D5293S and D5294S support Modbus communication over an RS-485 cable. Up to 127 modules can be arranged in a multi-drop network and monitored/configured by a single master unit, as shown in the following picture:

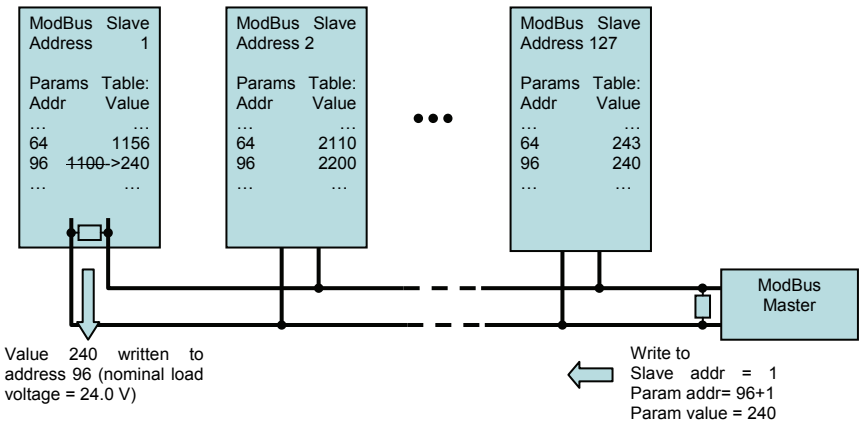


Note the presence of a termination resistance (typically 100 Ohm) at both ends of the Modbus cable: the furthest slave can be instructed to mount the termination resistance via dip-switch.
Modbus can be connected to each slave through the 5-pin bus connector; alternatively, it can be screwed to terminals 5 (A-) and 6 (B+) or 7 (A-) and 8 (B+). Each slave contains a table of parameters: each of them is univocally identified through an address and, when requested, makes available its value for reading/writing. In the picture above, the same two parameters are highlighted in all module slaves: the load voltage measured in the field (param addr: 64), the configured nominal load voltage (param addr: 96). In order to perform a read/write operation, the master must address the desired slave and parameter. Any parameter that can be read through the configurator is also available via Modbus; similarly, any parameter that can be written through the configurator may also be written via Modbus. The complete list of parameters, including address and format (number of decimals, binary encoding, etc…), is available in the instruction manual of the relay modules.

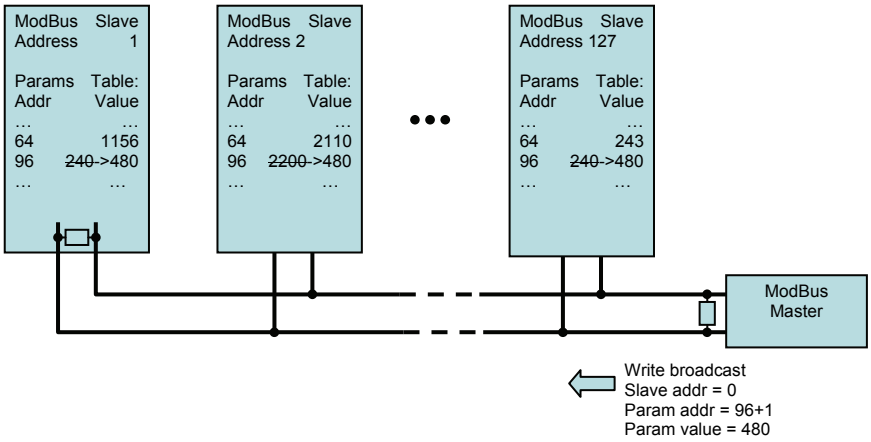
The following pictures show a few typical examples of communication between the master and the slaves.



The picture above indicates a read operation (Modbus command 3 or 4) performed by the master, addressing slave 2, parameter 64, therefore asking the slave 2 for the load voltage measured in the field. Note that the master must add a one to the parameter address, as requested by the Modbus standard. The slave returns the measured voltage expressed in hundreds of mV.

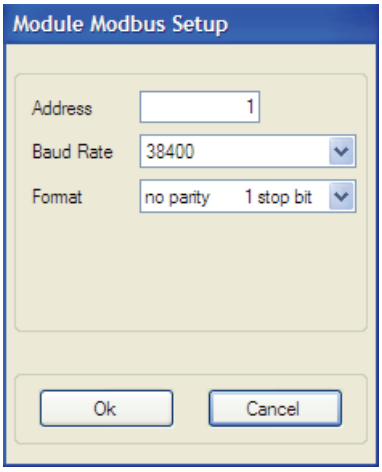


The picture above indicates a write operation (Modbus command 6 or 16) performed by the master, addressing slave 1, parameter 96, therefore asking the slave 1 to overwrite the nominal load voltage in its configuration. The slave replaces 110.0 V by 24.0 V at parameter address 96, and returns the written voltage expressed in hundreds of mV.



The picture above indicates a broacast write operation performed by the master, addressing slave 0, parameter 96, therefore asking all slaves to overwrite the nominal load voltage in their configuration. The slaves replace the old value by 48.0 V at parameter address 96: no answer is issued.

Before communicating through Modbus, each slave must correctly be configured through the serial interface. In the menu *"Settings->Modbus"* the user can access the *"Module Modbus Setup"* (picture below). The *Baudrate* can be selected among the different supported ones (4800, 9600, 19200, 38400, 57600, 115200), as well as the *Format* (no parity 1 stop bit, even parity 1 stop bit, odd parity 1 stop bit), which should cope with the Modbus Master. Each module should receive a different *Address*, between 1 and 127. Finally, the settings have to be saved onto the module, by pressing the *"OK"* button. Power cycling is necessary to make the Modbus settings effective.



5 Frequently Asked Questions

- *May D5293S/D5294S relay modules be used with loads other than solenoid valves?*

Both relay modules D5293S and D5294S are specifically designed for solenoid valves. Their usage with other kinds of loads, although not excluded a priori, should carefully be evaluated in the specific application context.

In particular, alarm horns and beacons for F&G applications often need termination resistances[2]. The following table gives a few indications for special loads:

What if …	**ND Loads and F&G**	**NE Loads**
In OFF state the load partially/totally activates	The D5294S cannot be used	The D5293S/D5294S cannot be used
In OFF state the *"Load OFF Resistance"* hits the saturation	Add around 2 or 3 kOhm termination resistance[2] in parallel to the load	No special requirements
In OFF state the *"Load OFF Resistance"* strongly oscillates	Add a termination resistance[2] in parallel to the load to reduce the fluctuation below 10 % the average value	No special requirements
In ON state the *"Load Current"* strongly oscillates	No special requirements	Add a termination resistance[2] in parallel to the load to reduce the fluctuation below 10 % the average value

- *Since both D5293S and D5294S relay module can switch NE loads, how to choose between them?*

In case of NE loads, both D5293S and D5294S relay modules can be used. The choice among them should be operated according to the following consideration: the D5293S maximizes the Tproof period for function safety at the expense of the availability; as opposed to that, the D5294S module maximizes the availability (hence minimizing the rate of false trips), but reduces the Tproof period for functional safety.

	D5293S with NE loads	**D5294S with NE loads**
SIL3 Tproof	10 years	7 years
Availability	99.826 %	99.995 %
Unavailability	174 E-3	5 E-3

- *How to configure the D5293S/D5294S when the real load is available?*

When the final actuator is available, the easiest and most accurate configuration consists in the automatic acquisition of the parameters. If the load is Normally Energized (Normally De-energized), the acquisition must be performed when the valve is ON (OFF).

[2] The termination resistance must be sized according to its power rating and the load supply voltage.

- *How to configure the D5293S/D5294S without a real load?*

Sometimes the final actuator is not available at the time of the software configuration. In this case, the best is to configure the modules with datasheet data. If not even these ones are available, the modules should be given very loose constraints, just to detect abrupt short and open circuit of the load.
In case of DC loads, datasheets normally indicate the operating voltage (V) and the current (I) or the power (P). The relay module configuration requires the application of the following equations:
$I = P/V$
$R = V^2/P = V/I$.

In case of AC loads, the situation is more complex. Datasheets normally indicate the operating voltage (V), the total power expressed in Volt x Ampere (P) and the active power expressed in W (Pr). In this case the equations become:
$I = P/V$
$R = V^2*Pr/P^2$

- *Which values can be monitored with NE loads? Which ones with ND loads / F&G?*

In Normally Energized (NE) applications, the quantities that can be monitored are:
1. *Load Supply Voltage*,
2. *Load Current*,
3. *Coil Integrity.*

The *Load OFF Resistance* is always at saturation (5000 Ohm), as well as the *Isolation Resistance* (3000 kOhm), hence they are not meaningful.

In Normally De-energized (ND) and F&G applications, the quantities that can be monitored are:
1. *Load Supply Voltage*,
2. *Load OFF Resistance*,
3. *Isolation Resistance*.

The *Load Current* is always zero, whereas the *Coil Integrity* is not evaluated.

- *Which ranges around the nominal values in the configuration make sense?*

The configuration ranges are strongly dependent on the application. Yet, in first approximation these guidelines may be followed:

Line Voltage	Load Current	Line OFF Resistance	Isolation Fault
±20%	±50%[3]	±50%[3]	-50%

[3] In case of a double-coil application, the range should be reduced to ±40% or less.