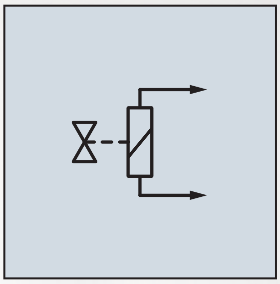
Application Guideline

Solenoid Valves – Solenoid Drivers

Manual



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1 Introduction

1.1 Content of this Document

This document contains information that you need in order to use your product throughout the applicable stages of the product life cycle. These can include the following:

- Product identification
- Delivery, transport, and storage
- Mounting and installation
- Commissioning and operation
- Maintenance and repair
- Troubleshooting
- Dismounting
- Disposal

Note

This document does not substitute the instruction manual.

Note

For full information on the product, refer to the instruction manual and further documentation on the Internet at www.pepperl-fuchs.com.

Note

For specific device information such as the year of construction, scan the QR code on the device. As an alternative, enter the serial number in the serial number search at www.pepperl-fuchs.com.

The documentation consists of the following parts:

- Present document
- Instruction manual
- Datasheet

Additionally, the following parts may belong to the documentation, if applicable:

- EU-type examination certificate
- EU declaration of conformity
- Attestation of conformity
- Certificates
- Control drawings
- Functional safety manual
- Additional documents

1.2 Target Group, Personnel

Responsibility for planning, assembly, commissioning, operation, maintenance, and dismounting lies with the plant operator.

Only appropriately trained and qualified personnel may carry out mounting, installation, commissioning, operation, maintenance, and dismounting of the product. The personnel must have read and understood the instruction manual and the further documentation.

Prior to using the product make yourself familiar with it. Read the document carefully.

1.3 Symbols Used

This document contains symbols for the identification of warning messages and of informative messages.

Warning Messages

You will find warning messages, whenever dangers may arise from your actions.
It is mandatory that you observe these warning messages for your personal safety and in order to avoid property damage.

Depending on the risk level, the warning messages are displayed in descending order as follows:

Danger!

This symbol indicates an imminent danger.

Non-observance will result in personal injury or death.

Warning!

This symbol indicates a possible fault or danger.

Non-observance may cause personal injury or serious property damage.

Caution!

This symbol indicates a possible fault.

Non-observance could interrupt the device and any connected systems and plants, or result in their complete failure.

Informative Symbols

Note

This symbol brings important information to your attention.

Action

This symbol indicates a paragraph with instructions. You are prompted to perform an action or a sequence of actions.

2 Intrinsically Safe Solenoid Valve Control

The interconnection of a field device with an isolated barrier depends on many factors. Field devices can be solenoid valves, indicators or audible alarms. In this case, the isolated barrier is a solenoid driver.

To ensure that the solenoid valves function properly and comply with the intrinsic safety, several factors must be considered. Use the technical data of the devices in a worst-case calculation to verify the operation of the solenoid valve under unfavorable conditions, such as:

- Tolerance variations: When tolerances for the solenoid valve and driver are at their extremes.
- Ambient temperature: When the ambient temperature increases.

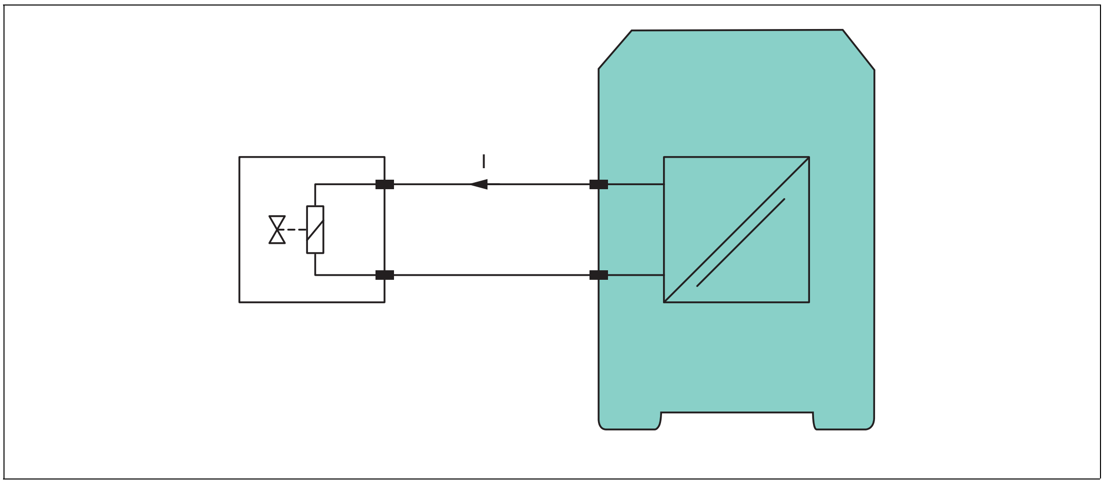

Figure 2.1 Connection of solenoid valve with solenoid driver

Intrinsic Safety Calculation

The safely limited energy values must be determined by verifying intrinsic safety. The verification of intrinsic safety is an integral part of the explosion protection document to be compiled before starting with installation work.

Note

For further information refer to **Type of Protection Intrinsic Safety** part of the explosion protection compendium.

3 The Solenoid Driver

In principle, the solenoid driver can be simplified as a voltage source

- with open loop voltage U_s
- with current limit I_e
- with internal resistance R_i.

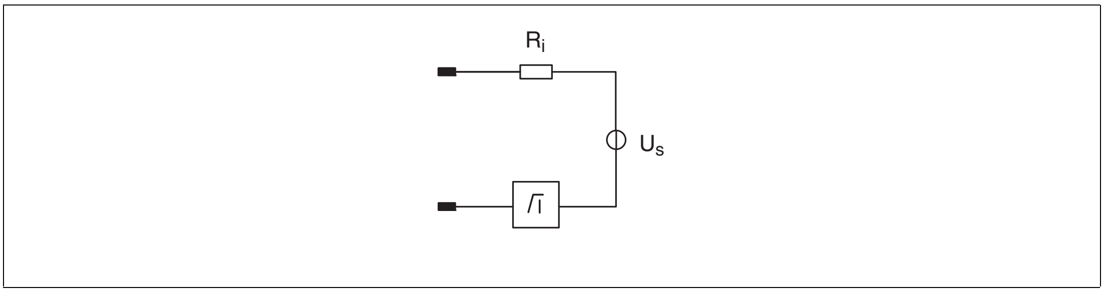

Figure 3.1 Output circuit diagram

The resulting output characteristic characterizes the different solenoid drivers in the Pepperl+Fuchs portfolio:

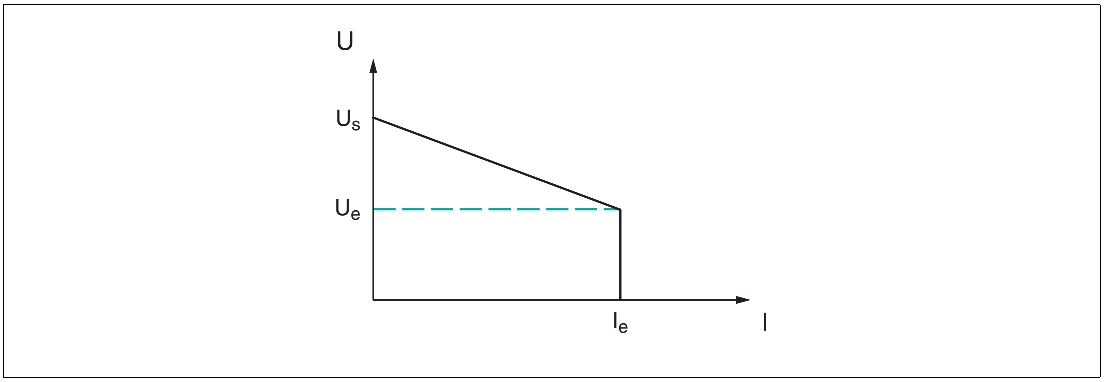

Figure 3.2 Output characteristic

The specifications for the key parameters described below can be found in the respective datasheets.

Some parameters, such as ones for line fault detection are only available for solenoid drivers supporting this functionality.

Open Loop Voltage U_s

The open loop voltage is the output terminal voltage with no field current (I = 0).

Internal Resistance R_i

The internal resistance reduces the available voltage depending on the output current of the solenoid valve. This resistance R_i is made up of Ex protection and other internal components.

Current I_e

If the current is reached, the active current limitation circuit is enabled. This current is the guaranteed minimum current.

Current Limit I_{max}

This current is the maximum value of the current limitation.

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Supported Load Resistance

This resistance is the resistive load that is supported during operation and line fault detection. A line fault is output for short circuit and lead breakage via the solenoid driver.

- Short circuit - resistive value below the operating range
- Lead breakage - resistance value above the operating range

Line Fault Detection Current I_{LFD}

Solenoid drivers inject a low test current into the field circuit in order to detect short circuits and lead breakages in the OFF state.

A low current of less than 500 µA and less is used for detection, which is limited to a low voltage. These restrictions prevent the current from affecting the normal operation of the solenoid driver.

This current can be found in the datasheets. As the current is linearly limited, it also depends on the impedance of the solenoid driver and can be calculated.

3.1 Line Fault Detection and Line Fault Transparency

Line Fault Detection

The line fault detection (LFD) is an important function that is integrated into isolated barriers for digital input and output signals.

The line fault detection is used to detect line faults such as short circuits and lead breakages between the isolated barrier and the field device.

This function is available in the ON and OFF state and enables continuous monitoring of the field circuit during operation.

Line Fault Transparency

The line fault transparency (LFT) is an evolution of the line fault detection that allows a complete integration of fault management into modern control systems.

The functional principle of the line fault transparency is to output a line fault present on the field side by increasing the input impedance to ∞ (open control loop) so that the control system recognizes an open control loop as a result.

By monitoring the control signals for line faults from the control system, faults in the field wiring of the isolated barrier are also clearly detected.

4 The Solenoid Valve

Looking at it from the simplest level, a solenoid valve can be seen as an electromechanical relay consisting of a coil with connected mechanism.

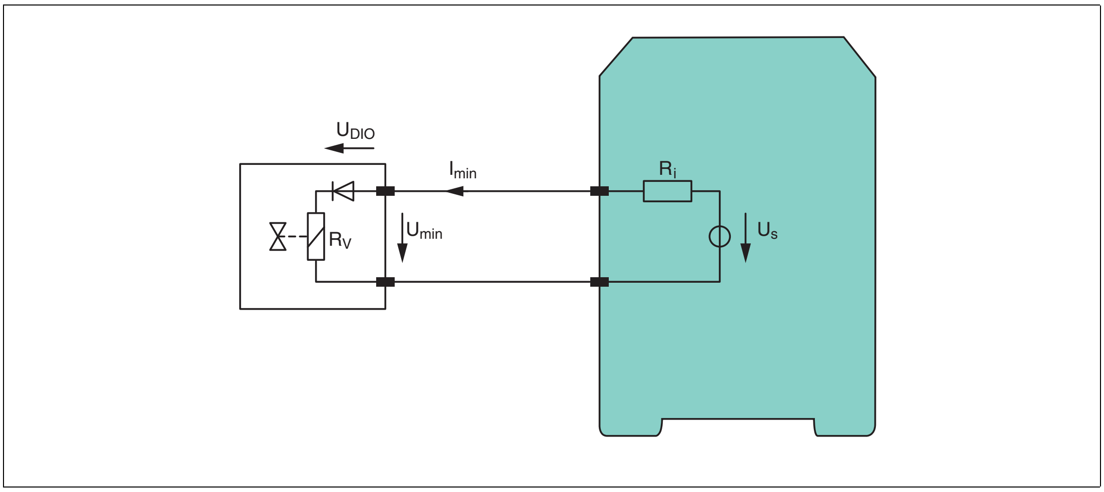

Figure 4.1 Electric signals in the solenoid valve and solenoid driver

The following parameters must be set in order to control a solenoid valve reliably.

Coil Resistance R_v

In calculations, the maximum coil resistance (at maximum operating temperature) should be used. The specific resistance of metals is temperature-dependent and increases with temperature. If the datasheet specifies only the resistance at the nominal temperature, then the factor 1.004/K (copper) can be used to calculate the value at maximum operating temperature.

Voltage U_{dio} of Internal Diodes

It is common that solenoid valves contain polarity protection diodes or bridges. In this case, the voltage drop U_{dio} of these diodes or bridges must be taken into account.

These values are rarely specified in the datasheets and are only of significance if U_{min} is not specified.

Minimum Switching Voltage U_{min}

The solenoid valve actuates above the minimum switching voltage. This value takes account of all internal voltage drops. If U_{min} is not specified, it can be calculated from I_{min}, R_v and U_{dio}.

Minimum Switching Current I_{min}

If the minimum switching current is exceeded, the solenoid valve is reliably actuated.

Holding Current I_{hold}

The holding current I_{hold} is a less relevant parameter in terms of its practical application in the case of classical solenoid valves; if the current falls below this value, the actuated solenoid valve is released again.

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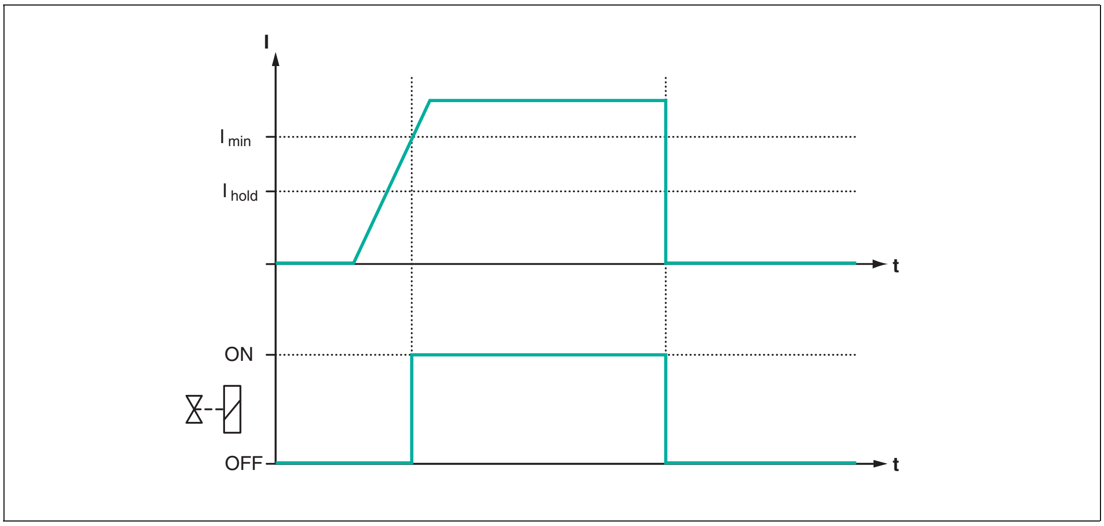

Figure 4.2 Solenoid valve current characteristic

Summary

Depending on the solenoid valve, not all operating parameters are specified, usually either the parameters U_{min} and I_{min} or the parameters I_{min}, R_v and U_{dio}.

With the most simple internal circuit of a solenoid valve, the following equation is valid. Missing parameters may be recalculated on this assumption.

$$U_{min} = U_{dio} + R_v \times I_{min}$$

5 Connection of Solenoid Valve with Solenoid Driver – Functional Calculation

Additional to the parameters of solenoid valve and solenoid driver, the line resistance has also to be considered.

Taking into account the maximum line resistance R_{Lmax} of the field wiring and using the technical data, a suitable solenoid driver for an existing solenoid valve can be determined. The aim is to find a line resistance that enables the field circuit to be operated.

In the following figure, the line resistance is shown in the field circuit.

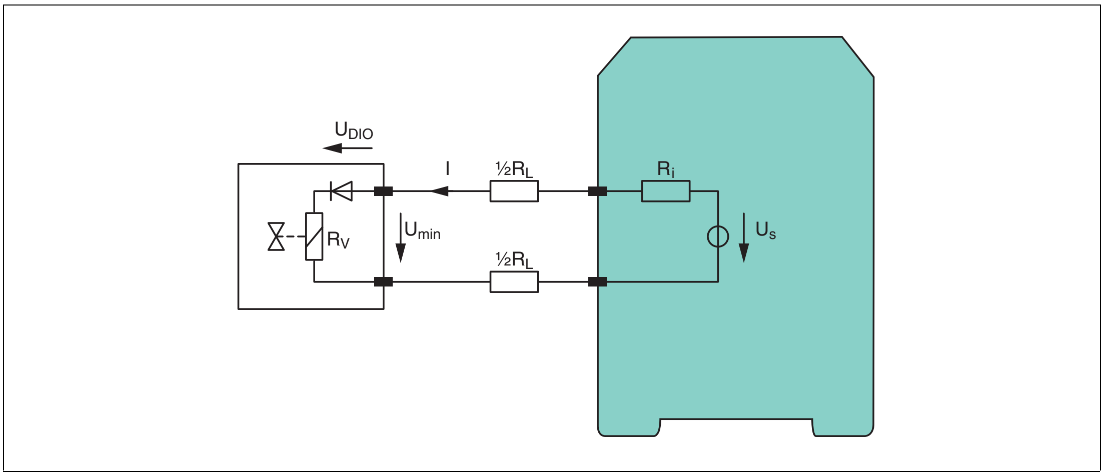

Figure 5.1 Field circuit with line resistance

Compare the minimum switching current of the solenoid valve with the maximum current that the solenoid driver can provide.

Equation 1
$I_{max} \geq I_{min}$

If the minimum voltage U_{min} is used for the calculation, calculate the voltage drop in the complete circuit as follows.

Reformulate the equation in terms of line resistance R_L. Calculate the line resistance R_L. The line resistance R_L must not be exceeded.

Equation 2
$U_s - U_{min} \geq (R_L + R_i) \times I_{min}$
$R_L = (U_s - U_{min} / I_{min}) - R_i$
$R_L > R_{Lmax}$

If the coil resistance R_v and the internal voltage U_{dio} is used for the calculation, calculate the voltage drop in the complete circuit as follows.

Reformulate the equation in terms of line resistance R_L. Calculate the line resistance R_L. The line resistance R_L must not be exceeded.

Equation 3
$U_s - U_{dio} = (R_L + R_i + R_v) \times I_{min}$
$R_L = (U_s - U_{dio} / I_{min}) - R_i + R_v$
$R_L > R_{Lmax}$

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In the equations 2 and 3, negative values of line resistance R_L mean that the operation cannot be guaranteed and another solenoid valve or solenoid driver have to be selected.

In some cases it can be specified a maximum coil temperature and relative coil resistance R_v for which operation is possible.

The functional connection of the solenoid valve and solenoid driver is exemplified using the following examples and the values specified on the data sheet.

Example 1

- **Solenoid valve**
  U_{min} = 19 V
  I_{min} = 13 mA
- **Solenoid driver**
  R_i = 272 Ω
  U_s = 24 V

The following maximum line resistance is derived from equation 2:

R_{Lmax} = (24 V - 19 V) / 0.013 A - 272 Ω = 113 Ω

For a specific cable resistance of 59 Ω/km (at 0.6 mm^2) the maximum cable length is calculated to be approx. 2 km. This ensures that the field circuit operates correctly.

Example 2

- **Solenoid valve**
  R_v (60 °C) = 4640 Ω
  U_{min} = 18.6 V
  I_{min} = 3.75 mA
- **Solenoid driver**
  R_i = 272 Ω
  U_s = 24 V

The following maximum line resistance is derived from equation 3:

R_{Lmax} = (24 V - 18.6 V) / 0.00375 A - 272 Ω = 1168 Ω

Here, too, correct operation is ensured.

6 The Electronically Enhanced Solenoid Valve or Booster Valve

Electronically enhanced solenoid valves or booster valves, are special valves with an integrated electronic circuit. This circuit optimizes the solenoid valve's performance while the solenoid valve being operated from an energy limited intrinsically safe circuit.

This can include a capacitive charging acting as **reserve** to provide a high peak current during the pull-in phase of the anchor after the circuit is charged. For such solenoid valves, the simplification described in the previous chapter needs to be stated more precisely.

As the limited energy of the solenoid driver is commonly too low to operate the anchor, an internal capacitive circuit will charge after it switched on. After a charging time, often depending on the charging current, an internal switch will trigger the stored energy into the coil, operating the anchor with a higher current.

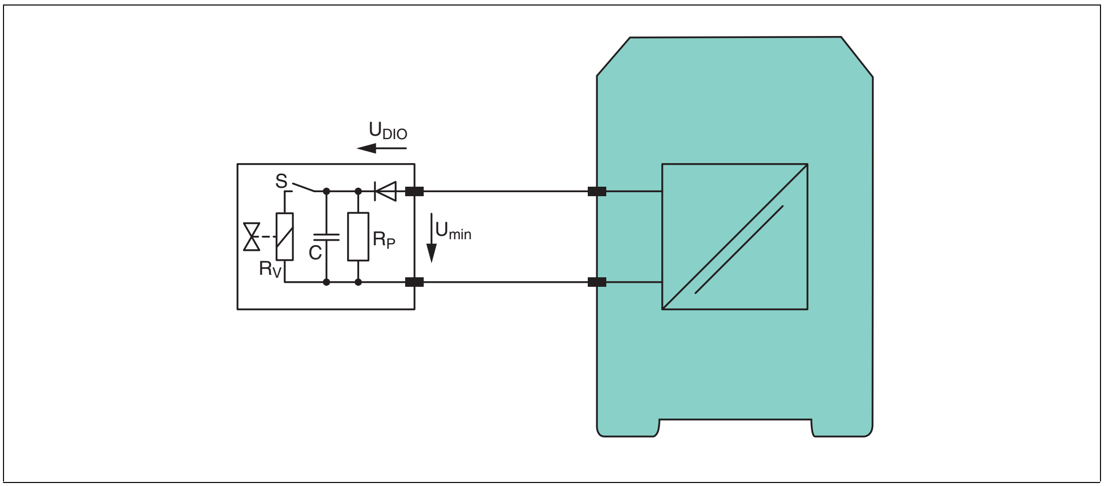

Figure 6.1 Electronically enhanced solenoid valve

The key parameters of electronically enhanced solenoid valves are:

Minimum Switching Voltage U_{min} or U_{boost}

As with the standard solenoid valves, the minimum switching voltage U_{min} is significant in this instance as well. After switching on the solenoid valve, the internal boost capacitor is charged until the energy required to actuate the solenoid valve is reached. This, together with the diode voltage, gives the minimum switching voltage that has to be applied to the solenoid valve terminals.

Holding Current I_{hold}

Once the solenoid valve has been actuated, it requires a minimum current I_{hold} to prevent it dropping off again.

Line Fault Detection Current I_{LFD} or I_{quiet}

Solenoid drivers inject a low test current into the field circuit in order to detect short circuits and lead breakages, see chapter 3. Ensure that this current does not interfere with the solenoid valve.

It is possible that the internal electronics do not allow a low current to flow. This results to a lead breakage, which is signaled by the solenoid driver. In this case, an external line termination resistor may be required, see chapter 7.

Voltage U_{dio} of Internal Diodes

The voltage drop U_{dio} of any polarity protection diodes that may be installed in the solenoid valve must be taken into account. These values are rarely specified in the data sheets and are only of significance if U_{min} is not specified.

7 Connection of Electronically Enhanced Solenoid Valve with Solenoid Driver

Taking into account the maximum line resistance R_{Lmax} and using the technical data, a suitable solenoid driver for a solenoid valve can also be determined. The aim is to find a line resistance that enables the field circuit to be operated.

The following figure shows the block diagram of an electronically enhanced solenoid valve and solenoid driver with line resistance.

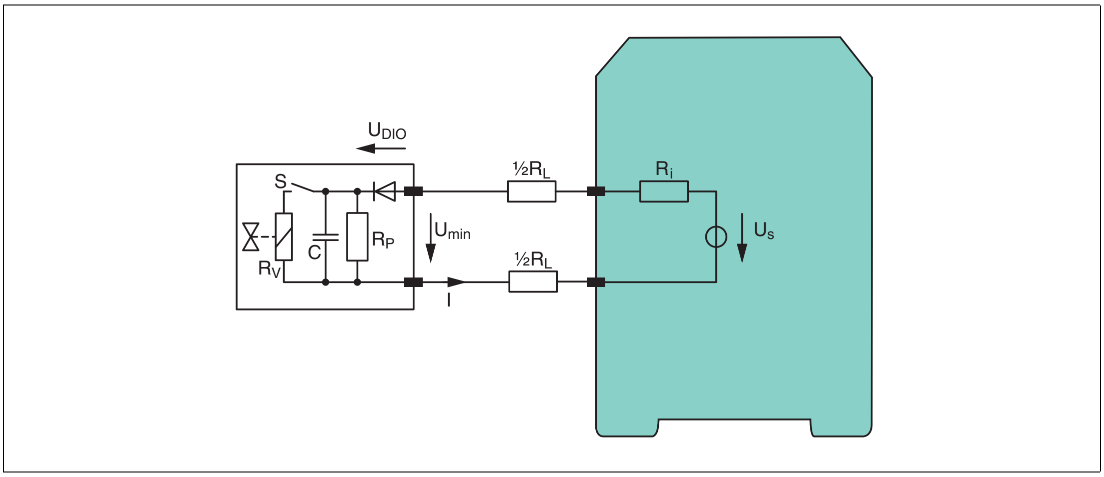

Figure 7.1 Electrical circuit with electronically enhanced solenoid valve

To make the behavior of the electronically enhanced solenoid valve easier to understand, the following figure shows the time response of the solenoid valve as it is switched on and off.

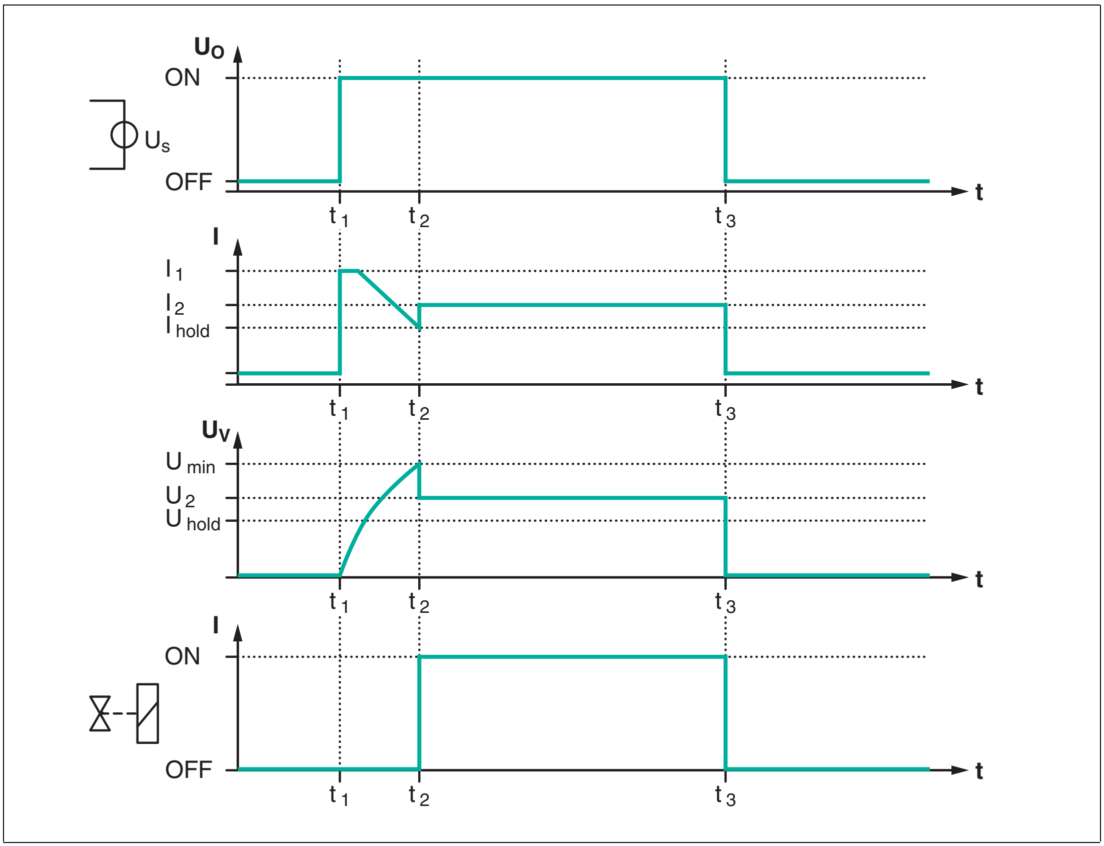

Figure 7.2 Time sequence when actuating the electronically enhanced solenoid valve

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Switching on at Time t_1

The solenoid driver switches U_s on the solenoid valve. The current I flows into the circuit, charging through the initially uncharged capacitor. The current I_1 is limited to the maximum value provided by the solenoid driver, as well by its internal resistance R_1 and the line resistance R_L.

The internal circuit charges, and the voltage increases up to the minimum switching voltage U_{min}. The open circuit voltage U_s provided by the solenoid driver must be greater than U_{min} in order for the solenoid valve to switch at all.

If specified, the minimum charging current I_{boost} shall be taken into account.

Equation 4
$U_s > U_{boost} + I_{boost} \times (R_L + R_i)$
$R_L = (U_s - U_{min} / I_{hold}) - R_i$

This line resistance R_L must not be exceeded.

Status after Switching on at Time t_2

The minimum switching voltage U_{min} of the solenoid valve is reached. The energy stored in the capacitor is used to actuate the solenoid valve, which causes the voltage to drop to U_2. The field current I adapts itself to the value I_2.

Equation 5
$I_2 = (U_s - U_{dio}) / (R_L + R_i + R_v)$
$R_{Lmax} < (U_s - U_{dio}) / I_2 - (R_i + R_v)$

The current I_2 must be greater than the holding current I_{hold} described above.
The parallel resistance R_p can be ignored in this case. If the holding voltage U_{hold} as well as the holding current I_{hold} is known, this parameter can also be used. This gives us the same situation as before using a classical solenoid valve.

Equation 6
$U_2 > U_{hold} = U_s - I_{hold} \times (R_L + R_i)$
$R_{Lmax} < (U_s - U_{hold}) / I_{hold} - R_i$

When choosing the solenoid driver, the conditions from equation 4, 5 or 6 must be met.

Line Fault Detection and Electronically Enhanced Solenoid Valve

The line fault detection current I_{LFD} is usually not sufficient to start up the electronics with the charging mimic of the capacitor.

Where the internal electronics of the solenoid valve do not allow a flowing current, the solenoid driver detects a highly resistive circuit, and a lead breakage is detected in such cases.

Connecting a line termination resistor parallel to the solenoid valve terminals or as close as possible to the solenoid valve could rectify the situation. The line fault detection of the solenoid driver can still be used, although it is not supported by the solenoid valve.

Line termination resistances are usually within the range of 4,7 kΩ to 15 kΩ.
Any resistance value within the valid range for the line fault detection of the respective solenoid driver can also be used.

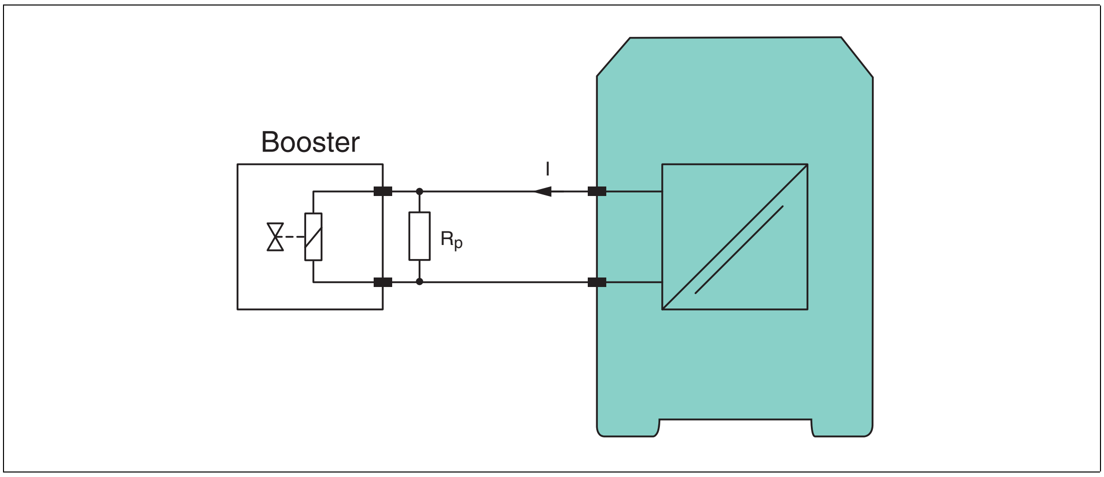

Figure 7.3 Parallel connected resistor near electronically enhanced solenoid valve

8 Specific Cable Parameters

The following cable resistances are used or assumed for calculations and examples in this document.

Conductor cross section	Specific resistance
0.6 mm^2	59 Ω/km
1.0 mm^2	35 Ω/km
1.5 mm^2	24 Ω/km

Table 8.1

According to IEC/EN 60079-14, the exact cable characteristics must be used as a basis for project planning.

The following maximum cable parameter are assumed for calculations and examples in this document.

Cable capacitance	1 mH/km
Cable inductance	0.12 µF/km

Table 8.2

9 Solenoid Valve Data and Calculation Sheets

Pepperl+Fuchs can provide calculation sheets for commonly used field devices on demand. Please get in touch with the local Pepperl+Fuchs subsidiary for detailed calculations.

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