

Current limiter

The invention relates to a current limiter for limiting overcurrents by means of a semiconductor element having at least one controllable semiconductor which has characteristic curves after the manner of a field-effect transistor (FET).

In the case of protective switchgear, such as power circuit-breakers, motor protective circuit-breakers or line protective circuit-breakers, in general in the case of automatic circuit-breakers, it is desirable rapidly to detect overload currents that occur, in particular short-circuit currents, and to limit them to the smallest possible values and finally to disconnect them. In the case of essentially mechanical automatic circuit-breakers, for example in the case of line protective circuit-breakers, use is made of so-called instantaneous releases, in which the magnetic circuit is of optimum design and also a magnet armature, often a plunger-type armature, rapidly and forcefully strikes open the contact system. Nevertheless, contact opening times of less than about 1 millisecond have still not been achieved in practice. The short-circuit current rises unimpeded here until the contacts open. An arc is not produced until after the contacts have opened, which arc is guided rapidly into an arc chamber and cooled on extinguishing plates during arc splitting. As a result of the high arc voltages in this case, the short-circuit current is limited and finally disconnected.

In the case of known automatic circuit-breakers, given a prospective short-circuit current of 6 kA, $\cos \phi = 0.6$ and $\psi = 60^\circ$, current-time values of less than the following are rarely obtained:

Switching current of 4000 A, rise time up to the peak value of 4 milliseconds, and an integral of the current squared over time of 30,000 A²s.

From time to time, it has already been proposed to use semiconductors for current limiting in protective switch-gear. This is impeded or prevented in practice by a variety of factors:

- 5 - Semiconductor elements generally have an inadequate current-limiting action and an excessively low permissible power consumption.
- In normal operation, semiconductor elements generally have a forward resistance of above 10 milli-
10 ohms at 16 A.
- Semiconductor elements generally have an excessively low dielectric strength as well.

The invention is based on the object of developing a current limiter from a semiconductor element having at
15 least one controllable semiconductor, in which the usual disadvantages hitherto of semiconductor circuits are reduced down to a technically feasible extent.

The object which has been outlined is achieved according to the invention by means of a current limiter according
20 to Patent Claim 1. In this case, the control voltage required for driving the semiconductor element is obtained from at least part of the load current flowing through the semiconductor element. The control voltage can also be obtained from at least part of the voltage
25 drop across the semiconductor element. The control voltage can also be obtained from a combination of the two provisions.

The means for driving using the voltage drop may in each case be a drive circuit connected to the drain and gate
30 of the semiconductor. A current/voltage converter situated in the load current is suitable in each case as the means for driving using the load current.

In the case of DC voltage, the drive circuit may in the simplest case comprise a resistor which is connected between the drain terminal and gate terminal of an FET. In the case of AC voltage, a drive circuit may be constructed in the simplest manner such that the drain terminals of two reverse-connected series FETs are connected to the gate terminals via a respective valve and via a resistor. A circuit of this type is suitable in conjunction with enhancement-mode FETs, that is to say with normally off FETs, which have an n-channel, as a starting circuit which enables the current limiter to run up to the operating state. A starting circuit of this type is not necessary if normally on FETs having an n-channel, that is to say depletion-mode FETs, are used, and depletion MOSFETs are particularly suitable.

In the case of DC voltage, a constant-current source which is connected between the drain terminal and the gate terminal is also suitable as the drive circuit. In the case of AC voltage, a drive circuit may advantageously be constructed such that the drain terminals of two reverse-connected series FETs are connected to the gate terminals via a respective valve and via a constant-current source.

A suitable current/voltage converter for driving using the load current is, in particular, a transformer whose secondary winding has connected to it an element which effects voltage limiting in both polarity directions, in particular to reverse-connected series zener diodes, and whose outputs are connected to the gate terminals via a rectifier circuit. The term "reverse-connected series zener diodes" in this case encompasses all those elements which have the action of a voltage-limiting zener diode. In the case of AC voltage, characteristic curves are then limited to a desired drain-source current in the first and third quadrants of a diagram with the drain-source current on the ordinate against the drain-source voltage on the abscissa.

The use of a transformer between two reverse-connected series FETs as an inductance for limiting short-circuit current is the subject-matter of one of the applicant's own European Patent applications which has an earlier
5 priority (Application Number 92 116 358.0, Figure 4, Figure 7). In this case, the transformer simultaneously serves to incorporate a control voltage to be applied externally.

In the case of the current limiter having a transformer
10 designed as a current/voltage converter, the drive voltage is obtained from the load current, that is to say internally. The advantage is furthermore obtained that the load current can be routed in a low-impedance primary winding having a small number of turns and that the
15 secondary side can be designed with high impedance and a large number of turns, in order to derive a voltage for the driving from the load current. The voltage-limiting element in this case ensures that the drain-source current is limited in a low-loss manner on a curve with
20 the corresponding parameter of the gate-source voltage.

It is advantageous to connect a rectifier circuit to a secondary winding of a transformer and to connect a capacitor in between DC voltage potential points for the drive voltage, specifically according to Claim 7. The
25 capacitor may optionally be formed by the gate-source capacitance of the FET, if this has a sufficient magnitude. When using voltage-limiting element [sic], it is advantageous to arrange them in a bridge circuit of zener diodes, specifically according to Claim 8.

30 In addition, the rectifier circuit may advantageously be designed as a voltage multiplier circuit according to Claim 9.

Finally, according to Claim 10, the current/voltage converter may be a chopper with a downstream-connected
35 voltage multiplier, as a result of which it is possible

to obtain the drive voltage from the load current without a transformer.

5 The solutions according to the invention and their advantages can be further promoted if the FETs are manufactured from silicon carbide, SiC. In this case the advantages known per se of an FET made of silicon carbide and the advantages of a current limiter according to one of the patent claims afford one another mutual support.

10 Current limiting in conjunction with means for driving using the voltage drop or the load current can be achieved in general by means of a circuit according to Claim 12.

15 In addition to obtaining the drive voltage internally, it is also possible, according to Claim 13, to provide on the semiconductor element a drive device for additional external driving. Corrective control voltages can then be applied externally. According to Claim 14, it is also possible, by means of external driving, to generate a voltage which blocks the semiconductor element when an
20 intended input signal is received. A current limiter of this type then acts as a circuit-breaker. A current limiter of this type can be constructed in general using semiconductors which have the particular properties which have been outlined. The current limiter may be designed
25 as an integrated circuit on a chip, using discrete components or with a mixed structure.

For certain applications, it may be advantageous to arrange at least one mechanical switching contact in series with the semiconductor element, according to Claim
30 15. A comparatively simple switching contact without any special extinction means is then sufficient, since the current rise is limited by the current limiter. On the other hand, when the switching contact has been opened, it protects the current limiter from sustained over-
35 loading. This interaction permits advantageous construc-

tions.

A protective circuit-breaker designed as an automatic circuit-breaker with two reverse-connected series FETs and a mechanical switching contact is known per se (PCT/EP 92/02678). In the case of this earlier protective circuit-breaker, which is constructed as a power circuit-breaker, a unit formed by relays and switching contacts is connected in parallel with two reverse-connected series FETs. In that case, too, the switching contacts are arranged in series with the interconnection of the FETs. However, the internal impedance of the semiconductor element has a low value at a specific control voltage, and as the voltage across the working electrodes rises, the internal impedance rises abruptly, with the result that the release element of the relay is supplied with voltage and can initiate the disconnection operation.

The mode of operation of the current limiter having a mechanical switching contact arranged in series is fundamentally different from this. According to Claim 16, the switching contact may be in engagement, either directly or indirectly via an energy storage mechanism, with a magnetic system which opens the switching contact in dependence on the current limiter.

A particularly favourable interaction of the semiconductor element and the magnetic system for the switching contact is achieved by means of a structure according to Claim 17. The magnetic system has a comparatively low-impedance primary winding with respect to the secondary winding and forms, on the one hand, the transformer for obtaining a control voltage from the load current. On the other hand, the magnetic system simultaneously forms with its low-impedance primary winding the exciter winding for that magnetic system whose armature is operatively connected to the switching contact. The effect achieved here is multiple use of structural elements in a combined

arrangement. In particular, the armature air gap can be bridged by an auxiliary yoke according to Claim 18, thereby producing a well-closed magnetic circuit for the current/voltage converter, which auxiliary yoke is
5 dimensioned in such a way that it reaches saturation even at comparatively small currents. As a result, both the functioning of the armature and that of the magnetic circuit for the current/voltage converter remain unimpaired in practice.

10 For this purpose, then, the operating air gap is bridged by an auxiliary yoke which is dimensioned in such a way that it reaches magnetic saturation even at currents which is [sic] less than the desired response current for the magnet armature.

15 The semiconductor element may be used in general in an automatic circuit-breaker, such as, for example, a power circuit-breaker, a line protective circuit-breaker or in a motor protective circuit-breaker or other protective devices, as a current-limiting part having the function
20 of a so-called limiter. It is understood that the semiconductor element and the mechanical switching contact may each be part of physically separate switching devices.

The invention will now be explained in more detail using
25 exemplary embodiments which are represented in a roughly diagrammatic manner in the drawing:

FIG 1 is a first, simplified exemplary embodiment of the current limiter, the driving or the control voltage being obtained from the voltage drop
30 across the semiconductor element.

FIG 2 illustrates a current limiter whose control voltage is obtained from the load current.

FIG 3 illustrates a current limiter whose control voltage is obtained from the voltage drop across
35 the semiconductor element.

FIG 4 illustrates a current limiter whose control voltage is obtained from the load current and from the voltage drop across the semiconductor element.

5 FIG 5 shows a twofold development of the current limiter. The control voltage is obtained from the load current in a particularly advantageous manner by means of a current/voltage converter between two reverse-connected series FETs. 10 Furthermore, a switching contact is inserted in series with the series limiter.

FIG 6 illustrates a current limiter having a switching contact, in which reverse-connected series zener diodes are arranged in a bridge circuit as voltage-limiting elements on the secondary side of 15 the current/voltage converter. A capacitor is connected in between the DC voltage potential points for the control voltage on the secondary side. A voltage-limiting element on the primary side is not necessary here. 20

FIG 7 diagrammatically illustrates the use of a voltage multiplier circuit for a current limiter according to Figure 6.

FIG 8 represents a different exemplary embodiment of a 25 current limiter for driving using the load current, according to which the current/voltage converter is designed as a chopper with a downstream-connected voltage multiplier.

FIG 9 illustrates the principle of control voltage 30 production from the load current with reference to the illustration according to FIG 5.

FIG 10 illustrates a further basic principle which is oriented to the illustration according to FIG 5 and according to which the control voltage 35 production is broken down when using a current/voltage converter by virtue of auxiliary voltage production on the secondary side and voltage production for the gates.

FIG 11 illustrates, with reference to the illustration

according to FIG 10, how it is possible to effect additional, external driving.

FIG 12 represents an alternative design for a command element for additional, external driving according to FIG 11.

FIG 13 shows an exemplary embodiment of a development of the current limiter, according to which a transformer as the current/voltage converter is designed in a manner combined with the magnetic system for actuating the switching contact.

FIG 14 represents at the top the detailed symbol for a normally off FET designed with an n-channel, and underneath this the corresponding, reduced symbol used in this application.

FIG 15 portrays a diagram which is intended to illustrate the mode of operation of the current limiter.

FIG 16 illustrates a magnetic system for the current limiter, whose operating air gap is bridged by an auxiliary yoke which is dimensioned in such a way that it reaches magnetic saturation even at currents which are less than the desired response current for the magnet armature.

The semiconductor element 1 according to FIG 1 operates in the exemplary embodiment with field-effect transistors 3, referred as FETs below. In the exemplary embodiment, the FETs 3, corresponding to the upper illustration in FIG 14, can be understood to be enhancement-mode FETs, which are normally off and have, for example, an n-channel. The reduced symbol used here is represented in the lower illustration according to FIG 14. FIG 1 illustrates a current limiter for AC voltage which operates with two reverse-connected series FETs 3 in the case of two polarities to be connected. In order to drive the semiconductor element, or the FETs, the required control voltage is obtained from the voltage drop by virtue of the fact that a series circuit formed by a valve 4, for example a diode, and a resistor 5 is connected to the

drain terminal 7 of each FET and, at the other end, is connected to the gate terminal 6 of the FET 3. In the case of AC voltage and two reverse-connected series FETs, therefore, a connection is established at the drain terminals 7 to the gate terminals 6 via a respective valve 4 and via a resistor 5. The source terminals 8 of the FETs 3 are connected to one another.

If only one potential is to be connected, the upper or lower FET 3 in conjunction with the assigned valve 4 and the resistor 5 are sufficient, with reference to FIG 1 for orientation. The source terminal 8 can then be routed to earth.

In the exemplary embodiment according to FIG 1, with two reverse-connected series FETs 3, a zener diode is connected as voltage-limiting element 9 in between the gate terminals 6 and the junction 10 of the source terminals 8 of the reverse-connected series FETs 3. The junction 10 carries the load current.

The gate voltage of the reverse-connected series FETs 3 is thus obtained via the valves 4 and via the resistor 5. The voltage-limiting element 9 limits the gate voltage, and hence a maximum flowing short-circuit current.

FIG 2 illustrates how the control voltage U_g is obtained as a function of the load current I , $U_g = f(I)$. FIG 3 illustrates that the control voltage U_g can be obtained as a function of the voltage drop U across the semiconductor element, $U_g = f(U)$. FIG 4 illustrates how the control voltage U_g can be obtained as a function of the load current and as a function of the voltage drop across the semiconductor element: $U_g = f(I)$ and $U_g = f(U)$.

In the development according to FIG 5, a mechanical switching contact 2 is connected in series with the current limiter. The current limiter operates with two reverse-connected series FETs, whose source terminals are

connected to one another via the primary winding 12 of a current/voltage converter 11. It is further essential in this case that an element 14 which effects voltage limiting in both polarity directions, in particular two reverse-connected series zener diodes 15, is connected to the secondary side, or in other words to the secondary winding 13, of the current/voltage converter 11. The zener diodes 15 connected on the secondary side limit the voltage on the secondary side, as a result of which only a voltage drop of a few tens of millivolts occurs on the primary side, owing to the transformation ratio of the current/voltage converter 11. Load current additionally flowing through the FETs 3 on the primary side is consequently limited by the low-loss limiting of the voltage on the secondary side by means of the current/voltage converter. This effect interacts with the semiconductor technology-dependent limiting caused by the special driving of the FETs 3. On the other hand, the transformation ratio of the current/voltage converter 11 permits a comparatively high voltage to be passed to the primary side as gate-source voltage, as a result of which the ON resistance is reduced. R_{ON} is obtained at large gate-source voltages. The details of the effect will be explained later with reference to FIG 15.

In the exemplary embodiment according to FIG 5, a rectifier circuit 16 is further connected to the secondary side of the current/voltage converter 11, which rectifier circuit is connected, on the one hand, to the gate terminal 6 of the FETs 3 and, on the other hand, via a centre tap 18 of the [sic] primary winding 12. In the exemplary embodiment, a capacitor 19 in the form of a storage capacitor satisfies two functions:

On the one hand, it isolates the DC voltage potential points 17 for the control voltage and, on the other hand, it ensures that, in the family of current/voltage characteristic curves of the semiconductor element 1 having the reverse-connected series FETs 3, it is not necessary each time to run up to the ON resistance between the para-

meter-dependent characteristic curves for the gate-source voltage in the first and third quadrants, but rather that it is possible to operate at the ON resistance between the first and third quadrants, even in the case of AC voltage. This will also be explained with reference to FIG 15. The capacitor 19 is used in this second function in the exemplary embodiment according to FIG 6. In that case, the DC voltage potential points 17 of the rectifier circuit 16 are, moreover, made available without the capacitor 19.

In the case of the current limiter according to FIG 5, the current/voltage converter 11 is not terminated as usual by a resistor, but by the zener diodes 15 of the voltage-limiting element 14. By means of the tapping of the DC voltage potential points 17, there is routed to the primary side of the converter a gate auxiliary voltage, which supplements or replaces the auxiliary voltage generation on the primary side such as was explained with reference to FIG 1. Given a zener voltage of approximately 9.1 V and a forward voltage of approximately 0.9 V across the zener diodes 15 in one direction, for example, a voltage having a magnitude of approximately 10 V is achieved on the secondary side of the current/voltage converter 11. If a current which is large enough to overcome the inductive reactance flows, therefore, in the primary winding 12, a voltage is established on the primary side, on account of the 10 V on the secondary side, corresponding to the transformation ratio of the current/voltage converter 11. For example, given a transformation ratio of 1 to 1000, a voltage of only 10 mV occurs, therefore, at the primary winding 12.

The circuit according to FIG 5 functions in detail as follows:

If a voltage is present at the terminals 20 and 21 of the automatic circuit-breaker, for example owing to a switched-on load, a current flows via the valves 4, or

the diodes, depending on the polarity of the AC voltage, and a reduced positive potential is present at the gate terminals 6 owing to the voltage drop across the resistor 5 with respect to the positive terminal voltage at 20, with the result that an opening gate-source voltage is present at the FETs 3 and the drain-source paths are brought into the ON state. The current flowing through the primary winding 12 of the current/voltage converter 11 generates a voltage across the high-impedance secondary winding, which voltage is limited, when the zener voltage of the upper or lower zener diode 15 is reached, to the zener voltage plus the forward voltage of the other zener diode, to be precise in both directions of current flow assigned to the AC voltage. In this case, there is produced at the secondary winding 13 a virtually rectangular-waveform AC voltage which produces, via the diodes 22 for rectification in the circuit of a full-wave rectifier, at the capacitor 19, a DC voltage having the magnitude of the zener voltage of each of the zener diodes 15. This DC voltage is fed to the two gate-source junctions of the FETs 3, as a result of which the latter are maintained in the ON state without further requiring a voltage drop across the resistor 5. In other words: current then no longer flows through the resistor 5.

In the exemplary embodiment according to FIG 6, the voltage-limiting element 14 is constructed in the form of a bridge circuit comprising four zener diodes 15. In the case of this circuit, a current-limiting element 9 is not necessary on the primary side of the current/voltage converter 11. A switching contact 23 is again arranged in series.

The amplitudes of the AC voltage in the secondary winding 13 of the current/voltage converter 11 can be kept smaller if a voltage multiplier circuit 24 is connected downstream of the voltage-limiting element 14, as is illustrated in FIG 7.

For driving using the load current, the current/voltage converter can be designed according to FIG 8 as a chopper 39 with a downstream-connected voltage multiplier circuit 24. The voltage occurring across a resistor 55 in the event of load current is present at the chopper 39. In order to limit the voltage drop and in order to minimize the power loss, it is advantageous to provide a voltage-limiting means 40. In the exemplary embodiment, that may be two reverse-connected parallel diodes which limit the voltage drop across the resistor 5 to the forward resistance of the diodes.

FIG 9 diagrammatically represents the generation of the control voltage between the gate terminals 6 and the source terminals 8 of the field-effect transistors 3. The generation of the control voltage can be split between control voltage generation 25 in the starting case and auxiliary voltage generation 26, such as was explained in detail with reference to FIG 5.

FIG 10 diagrammatically illustrates the structure of a current limiter having a control voltage supply 25 and an auxiliary voltage supply 26. The control voltage supply 25 can be designed as a starting circuit, with the result that the control voltage during operation is then undertaken by the auxiliary voltage supply 26.

In order to be able to drive the semiconductor element externally in addition, it is possible to provide an external drive device 41 according to FIG 11. If actuating contacts 42 are closed, the gate-source voltage is short-circuited, with the result that a normally off FET passes into the off state.

The external drive device 41 can also operate with semiconductor contacts 43 according to FIG 12.

FIG 13 illustrates, on the one hand, an advantageous refinement of the arrangement according to FIG 10, the

auxiliary voltage production being implemented in the form of a voltage multiplier circuit, and represents, on the other hand, a development according to which the low-impedance primary winding is operatively connected to an armature 27 which is to be brought into engagement with the switching contact 23. A design of this type is particularly cost-effective, since the current/voltage converter 11 and the magnetic system 36 which opens the switching contact via the armature 27 are structurally and functionally combined. An energy storage mechanism 38 like a latch may additionally be provided. In this case, a high-impedance winding having a large number of turns can be fitted as the secondary winding 13 to the low-impedance primary winding 12 which drives the armature. In this case, a small auxiliary yoke 37, compare FIG 16, may close the magnetic circuit for the functioning of the current/voltage converter 11. This auxiliary yoke is advantageously dimensioned in such a way that it reaches saturation even at comparatively small currents, with the result that the functioning of the armature 27 which acts on the switching contact 23 is practically unaffected. The low-impedance primary winding 12 may comprise a small number of turns, for example 2 to 4 turns, and a favourable voltage range for the auxiliary voltage production can be raised on the secondary side up to a desired voltage value by means of the voltage multiplier circuit. The voltage multiplier circuit comprises the components: capacitors 28 and 19, the capacitors 19 simultaneously providing the DC voltage for driving the FETs 3, as well as the diodes 29, which at the same time effect rectification in the circuit that is represented.

The control supply 25 according to FIG 13 presents one possible way of producing a "fall-back" characteristic curve. The essential components for this are the transistor 30 and the resistors 31, 32 and 33. This section of the circuit operates as follows:

When the current-limiting action of the FETs 3 begins on account of an increased current, such as occurs, for

example, in the event of a short circuit, the voltage across the terminals 20 and 21 rises. This voltage appears at the bridge rectifier, which is formed by the diodes of the valves 4 and the body diodes, also referred to as inverse diode, of the FETs 3. A body diode is known to be the internal diode wiring, associated with each depletion layer, in particular an MOSFET, of the pn junction from the source to the drain. The body diodes are illustrated with the designation 31. The voltage present at the depicted bridge rectifier is also present at the series circuit formed by the resistors 131 and 133, as a result of which a voltage drop occurs across the resistor 133 and switches the transistor 30 on. Due to the size of the resistor 132, a gate-source voltage can be turned on which becomes smaller and smaller as the voltage across the terminals 20 and 21 rises, and thus reduces a load current through the FETs 3. The exemplary embodiment that is represented shows only one possible way of producing a fall-back characteristic curve in accordance with the principles according to the invention. Any desired characteristic curve can be produced, as is known, using an operational amplifier.

In FIG 14, the complete symbol for a FET is reproduced in the top illustration and the reduced symbol as used in the present description is represented in the bottom illustration. The usual abbreviations for drain, gate and source are entered, as well as the positive direction of the drain-source current. The illustration according to FIG 14 shows an enhancement-mode FET, that is to say a normally off FET which has an n-channel. The illustration according to FIG 14 is to be understood, in particular, as an MOSFET. It is understood that the circuits that have been represented according to Figures 1 to 13 may also be realized by other corresponding components, in particular by other FETs. When using p-channel FETs, therefore, it is necessary to carry out only the usual polarity reversal. It is essential that characteristic curves such as those illustrated in FIG 15 can be

realized, in other words that, for DC voltage, a maximum current can be set independently of the voltage, and that, for AC voltage, conditions of this type prevail in two diagonally opposing quadrants. The circuits which
5 have been represented here by way of example using specific FETs are to be regarded in this general sense.

Reference will be made to FIG 15 to explain functional principles of the current limiter:

FIG 15 shows a diagram where the drain-source current I_{DS}
10 is plotted on the ordinate and the drain-source voltage U_{DS} is plotted on the abscissa. An FET of the type depicted here, such as the one explained with reference to FIG 14, originally has a characteristic curve 32 which changes into the characteristic curve 33 of the body
15 diode in the event of a negative drain-source voltage. The horizontal characteristic curves are produced for a gate-source voltage parameter and limit the drain-source current with corresponding circuitry. A steep ON
20 resistance, R_{ON} , is achieved at high gate-source voltages. With reverse-connected series FETs in the case of AC voltage, a symmetrical mode of operation is achieved between the first and third quadrants, the characteristic curve 33 of the body diode no longer being realized. The use of a circuit with a current/voltage
25 converter having the circuitry depicted achieves a rise following the characteristic curve 35, which merges with the straight line for the physically predetermined ON resistance of the FET used.

A rise for each polarity direction of an AC voltage is
30 avoided in a reverse-connected series arrangement of FETs when a capacitor 19 is used as a storage capacitor in the manner described. The current-limiting action of the reverse-connected series FETs then develops between a selected horizontal characteristic curve with the corre-
35 sponding gate-source voltage as the parameter in the first and third quadrants in conjunction with a transition in the characteristic curve 34 for the ON resis-

tance. In this case, the area between the characteristic curve 32 and a selected characteristic curve situated on the left in the first quadrant has the effect of a saving in loss, as evinced by the product of the drain-source current and the drain-source voltage. The possibilities of the principles depicted are further promoted in a considerable manner by the use of FETs made of silicon carbide. The semiconductor element 1, which is connected in series with the switching device, can be completely or partly realized as an integrated circuit in the various embodiments. The current limiter can also be used in a wide variety of applications without the switching device.

FIG 16 illustrates a magnetic system 36 having a primary winding 12, a secondary winding 13, an auxiliary yoke 37 and an armature 27. A magnetic system of this type is advantageous for the structural combination of a current limiter with a switching device, this already having been explained.

Patent Claims

1. Current limiter for limiting overcurrents by means of a semiconductor element (1) having at least one controllable semiconductor (3) having an electron source
5 (source), an electron sink (drain) and a control electrode (gate) which controls the flow of electrons, which semiconductor has characteristic curves after the manner of a field-effect transistor (FET;3), two FETs being reverse-connected in series, if appropriate, in the case
10 of AC voltage, and means being provided for internally obtaining the control voltage required for driving the semiconductor elements (1) from at least part of the voltage drop across the semiconductor element.
2. Current limiter according to Claim 1, characterized in
15 that the means for driving using the voltage drop is in each case a drive circuit connected to the drain (7) and the gate (6) of the semiconductor (3).
3. Current limiter according to Claim 1, characterized in that the means for driving using the load current is in
20 each case a current/voltage converter (11) situated in the load current.
4. Current limiter according to Claim 2, characterized in that, in the case of DC voltage, the drive circuit comprises a resistor (5) which is connected between the
25 drain terminal (7) and the gate terminal (6), and in that, if appropriate, in the case of AC voltage, the drain terminals (7) of the two reverse-connected series FETs are connected to the gate terminals (6) via a respective valve (4) and via a resistor (5).
- 30 5. Current limiter according to Claim 2, characterized in that, in the case of DC voltage, the drive circuit comprise [sic] a constant-current source which is connected between the drain terminal (7) and the gate terminal (6), and in that, if appropriate, in the case of



AC voltage, the drain terminals (7) of the two reverse-connected series FETs are connected to the gate terminals (6) via a respective valve (4) and via a constant-current source.

5 6. Current limiter according to Claim 3, characterized in that a current/voltage converter used takes the form of a transformer whose secondary winding (13) has connected to it an element (14) which effects voltage limiting in both polarity direction [sic], in particular two reverse-
10 connected series zener diodes, and whose outputs are connected to the gate terminals (6) via a rectifier circuit (16).

7. Current limiter according to Claim 6, characterized in that a rectifier circuit (16) is connected to the
15 secondary winding (13) of the transformer, the DC voltage potential points (17) of which rectifier circuit is [sic] connected, on the one hand, to the gate terminals (6) of the FETs (3) and, on the other hand, via a centre tap (18) of the [sic] primary winding (12), and in that a
20 capacitor (19) is connected in between the DC voltage potential points (17) for the control voltage.

8. Current limiter according to Claim 3, characterized in that a bridge rectifier formed by zener diodes is arranged on the secondary winding (13) of the trans-
25 former, the DC voltage outputs of which bridge rectifier are connected to the gates.

9. Current limiter according to Claim 6, characterized in that the rectifier circuit is constructed as a voltage multiplier circuit (24).

30 10. Current limiter according to Claim 3, characterized in that the current/voltage converter is a chopper with a downstream-connected voltage multiplier.

11. Current limiter according to one of the preceding



claims, characterized in that the semiconductors (3) are made of silicon carbide (SiC).

12. Current limiter according to Claim 1, 2 or 3, characterized in that an element (9) having the action of a
5 current-limiting zener diode is connected in between the gate terminal or terminals (6) and the source terminal (8) or the junction (10) of the two source terminals, which element is dimensioned in such a way that the gate
10 voltage of the semiconductor or of the semiconductors is set to a value at which the desired limiting of the overload current is established.

13. Current limiter according to one of the preceding claims, characterized in that a drive device for additional, external driving is constructed on the semicon-
15 ductor element (1).

14. Current limiter according to Claim 13, characterized in that the drive device is designed to generate a voltage which blocks the semiconductor element (1) when an intended input signal is received.

20 15. Current limiter according to one of the preceding claims, characterized in that at least one mechanical switching contact (23) is connected in series with the semiconductor element (1).

25 16. Current limiter according to Claim 15, characterized in that the switching contact (23) is in engagement with a magnetic system (36), either directly or indirectly via an energy storage mechanism (38).

30 17. Current limiter according to Claim 16, characterized in that the magnetic system (36) has a comparatively low-impedance primary winding (12) with respect to the secondary winding (13) and on the one hand forms the transformer for obtaining a control voltage from the load current and on the other hand simultaneously forms with



its low-impedance primary winding (12) the exciter winding for the respective magnetic system whose armature (27) is operatively connected to the switching contact (23).

5 18. Current limiter according to Claim 17, characterized in that the operating air gap of the magnetic system (36) is bridged by an auxiliary yoke (37), which is dimensioned in such a way that it reaches magnetic saturation even at currents which are less than the desired response
10 current for the magnet armature (27).

19. Current limiter according to one of Claims 15 to 18, characterized in that the semiconductor element (1) is used in an automatic circuit-breaker, such as a power
15 circuit-breaker, a line protective circuit-breaker or motor protective circuit-breaker or the like, as a current-limiting part having the function of a limiter.

20. Current limiter according to Claim 15, characterized in that the semiconductor element (1) and the mechanical switching contact (23) are each part of physically
20 separate switching devices.

