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COORDINATION OF CURRENT-LIMITING FUSES AND CIRCUIT
INTERRUPTERS FOR THE PROTECTION OF
SEMI-CONDUCTOR RECTIFIERS

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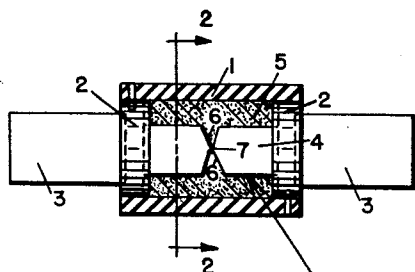


Fig. 1

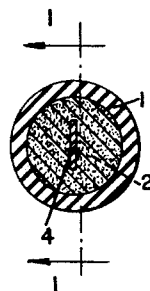


Fig. 2

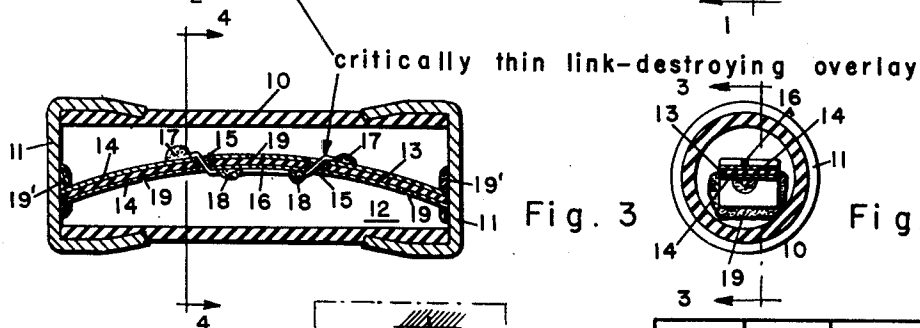


Fig. 3

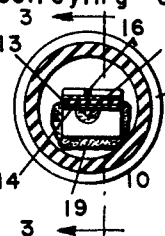


Fig. 4

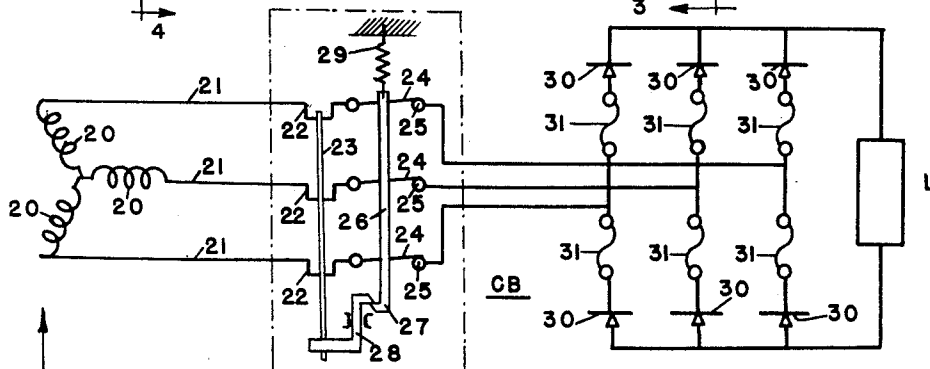
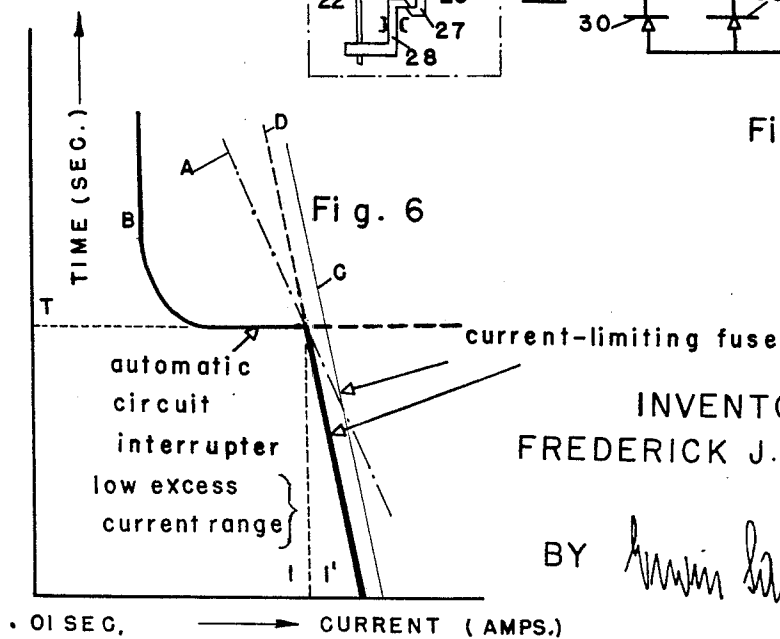


Fig. 5



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**COORDINATION OF CURRENT-LIMITING FUSES
AND CIRCUIT INTERRUPTERS FOR THE PRO-
TECTION OF SEMI-CONDUCTOR RECTIFIERS**

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6 Claims. (Cl. 321—14)

This invention refers to protection of semiconductor rectifiers by the coordinated action of current-limiting fuses and of automatic circuit interrupters having separable contacts.

The speed of operation of a current-limiting fuse increases the smaller the mass of metal in the fusible element that must be brought up to fusing temperature and fused to initiate arcing and concomitant build-up of arc voltage. For this reason current-limiting fuses which are intended to operate rapidly are often provided with fusible elements in the form of thin wires. Current-limiting fuses having fusible elements in wire form tend to have but a relatively limited current-carrying capacity. Where it is desired to combine highest possible speed of response with substantial current-carrying capacity it becomes necessary to apply as fusible elements short ribbons, preferably of silver, having a portion of restricted cross-sectional area sufficiently narrow and sufficiently short to approximate a point-heat-source when the ribbon is carrying current. Current-limiting fuses of this character are disclosed in United States Patent 2,734,111 to Frederick J. Kozacka, February 7, 1956, Low-Voltage High-Capacity Current-Limiting Fuses, and in United States Patent 2,781,434 to Kenneth W. Swain, February 12, 1957, Current-Limiting Fuses Comprising Fuse Links of Silver and Copper. The small point-heat-source neck, or portion of restricted cross-sectional area, of the fusible element or fuse link of such fuses minimizes the required fusion $\int i^2 \cdot dt$, and thus enables to obtain a high speed of response in the range of fault currents which are a predetermined multiple of the rated current of the particular fuse. In case of relatively large fault currents the heat generation at the point-heat-source neck is so rapid that fusion of the neck occurs before any appreciable heat transfer from the neck to the portions of the link can occur whose cross-sectional area is relatively large. As a fair approximation, heat transfer may be neglected wherever the heating period or pre-arcing period is less than 1 cycle of a 60 c.p.s. current wave. Where a ribbon fuse link with a point-heat-source neck carries relatively small overcurrents, heat generation at the point-heat-source neck occurs at a relatively small rate. Consequently the neck temperature tends to rise but relatively slowly, thus providing ample time for heat transfer from the neck to the wide portions of the link, i.e. to the portions thereof having a relatively large cross-sectional area, from where the heat is further dissipated. Consequently, i.e. because of the heat dissipation phenomena preceding fusion of, and arc initiation at, the neck, such fuses tend to involve a substantial time lag, or time delay, in the small overcurrent range.

The operating or fusing characteristic of a ribbon fuse link made of a high conductivity, low fusing energy metal, preferably silver, or possibly copper, and provided with a neck, or point of reduced cross-sectional area, depends entirely upon the particular geometry of the fuse link under consideration. A ribbon fuse link which has the smallest neck dimensions compatible with di-

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mensional stability requirements and whose normal width is dictated by given substantial current-carrying requirements has a fusing characteristic which is entirely determined by its geometry. The operating or fusing characteristic of a ribbon fuse link which is entirely determined by the geometry of the ribbon is not entirely satisfactory. Some applications as, for instance, silicon rectifier protection, require faster response or blowing times, both in the current range wherein heat exchange is insignificant, and in the current range wherein heat exchange is significant.

It is, therefore, a general object of the invention to provide protective means responding sufficiently rapidly to excess currents in both aforementioned excess current range and in the low excess current ranges.

A more specific object of the invention is to provide protective systems for semiconductor rectifiers comprising current-limiting fuses including ribbon links having a point of restricted cross-sectional area sufficiently short and sufficiently narrow to approximate a point-heat-source when carrying an electric current, which protective systems have response characteristics other than the response characteristics determined by the aforementioned geometrical configuration of the fuse link, and which protective systems operate considerably faster both in the range of relatively high excess currents and in the range of relatively small excess currents than in accordance with the determination of the speed of response based on the geometrical configuration of the fuse link.

Still another object of the invention is to provide means for establishing reclosable breaks in the protected circuit if the overcurrent therein is relatively small, and to provide means for establishing non-reclosable breaks in the protected circuit if the excess current therein is relatively large.

Another object of the invention is to provide protective systems for semiconductor rectifiers, and more particularly rectifier bridges, comprising a relatively large number of rectifier cells, which systems are provided with selective means for clearing fault currents resulting from actual or impending cell failure and for clearing small overload currents resulting from external faults or overloads.

Still another object of the invention is to provide protective systems for semiconductor rectifiers wherein the rectifier cells are arranged in series with current-limiting cell fuses and wherein the cell fuses are adapted to generate relatively high arc voltages and to minimize the arcing $\int i^2 \cdot dt$ incident to interruption below values normally encountered with silver-sand fuses.

Further objects and advantages of the invention will become apparent as the following description proceeds, and the features of novelty which characterize the invention will be pointed out with particularity in the claims annexed to, and forming part of, this specification.

For a better understanding of the invention reference may be had to the accompanying drawing wherein:

Fig. 1 is a section along 1—1 of Fig. 2, and shows a prior art current-limiting fuse;

Fig. 2 is a section along 2—2 of Fig. 1;

Fig. 3 is a section along 3—3 of Fig. 4 and shows a current-limiting fuse applied for carrying the invention into effect;

Fig. 4 is a section along 4—4 of Fig. 3;

Fig. 5 is a circuit diagram of a rectifier system embodying the invention; and

Fig. 6 is a time-current curve of the circuitry shown in Fig. 5, both the abscissae and the ordinates being plotted on a logarithmic scale.

Referring now to the drawing, and more particularly to Figs. 1 and 2 thereof, numeral 1 has been applied to indicate a casing of insulating material which is closed

on both ends by terminal elements 2 in the form of copper plugs. Each plug 2 is provided with a connecting contact 3 in the form of a blade, and both plugs 2 are conductively interconnected by a ribbon fuse link 4 of a high conductivity low fusing energy metal such as silver. Fuse link 4 is embedded in a pulverulent arc-quenching filler 5, such as chemically pure quartz sand. Two substantially V-shaped lateral incisions 6 in fuse link 4 define a point 7 of greatly reduced cross-sectional area. The thickness of link 4 is small, say in the order of .015", and the point of greatly reduced cross-sectional area or neck 7 is sufficiently short and sufficiently narrow to approximate a point-heat-source when link 4 is carrying an electric current. It is important that point 7 of link 4 be of silver; the adjacent axially outer portions of link 4 which have a relatively large cross-sectional area might be made of copper, if desired. A multimetallic fuse link of this character adapted for current-limiting fuses is disclosed in United States Patent 2,781,434 to Kenneth W. Swain, Current-Limiting Fuses Comprising Fuse Links of Silver and Copper, February 12, 1957, and reference may be had to that patent for additional information on the above subject. A fuse as shown in Fig. 1 lends itself relatively well to the protection of semiconductor rectifiers because its time current curve comes close to that desired for that particular application or, in other words, matches closely with the damage characteristic of very sensitive rectifier cells. The fuse shown in Fig. 1 is, however, too slow in the range of overloads less than 3 times its current rating. Furthermore the quartz filler 5 forms fulgurites when fused under the heat of an arc kindled in the fuse, which fulgurites shunt the arc gap when hot and forming good conductors of electricity. Such arc-gap-shunting fulgurites are conducive to relatively high values of the arcing $\int i^2 \cdot dt$ and tend to give rise to small leakage currents flowing through the fuse upon interruption of the circuit by it. These undesirable features must be eliminated if a fuse of the type illustrated in Fig. 1 is to be fully adapted for the protection of highly critical rectifier cells such as, for instance, silicon rectifier cells. The difficulties encountered by the formation of arc-gap-shunting fulgurites can be avoided by providing blast action arc extinguishing means as will be shown below more in detail. The speed desirable for semiconductor rectifier applications at current ratings above 3 to 5 times current rating can be achieved by relying on corrosion of the base metal of the fusible element by an overlay of a metal having a lower fusing point than the base metal. To this end the reduced cross-section portion 7 of link 4 is provided with a critically thin link-destroying low-fusing point metal overlay. What is meant by the words "critically thin" will be described below in greater detail. The link-destroying overlay may, for instance, be of tin, or an alloy of tin. As an alternative, the overlay may be of indium, or an alloy of indium.

While fuses of the type shown in Figs. 1 and 2 having fusible elements with a critically thin overlay capable of corroding the base metal are adequate for semiconductor rectifier cell protection at currents in excess of three times current rating as far as speed requirements are concerned, such fuses are not adequate for semiconductor rectifier cell protection in other respects. As mentioned above, the arc that forms upon fusion of the fusible element converts the surrounding quartz filler into a fulgurite which is a semiconductor when hot and unduly increases the arcing $\int i^2 \cdot dt$ of the fuse and the post current zero leakage current through the fuse. These drawbacks can be eliminated by removing or omitting the filler 5 of quartz sand, but such omission calls for a derating of the voltage for which the fuse is applicable. According to this invention the fuse is provided with blast action quenching means adapted to preclude formation of an arc-gap-shunting fulgurite upon fusion of the fusible link or fusible element and inception of an arc.

A fuse structure embodying this additional feature has been shown in Figs. 3 and 4.

Referring now to Figs. 3 and 4, numeral 10 has been applied to indicate an insulating casing closed on both ends by metal caps 11 which are crimped at the axially inner edges into casing 10 to effect a firm mechanical connection between casing 10 and caps 11. Casing 10 houses a strip of laminated material, generally indicated by the reference numeral 12. Strip 12 is resilient, and bent, and rests with the axially outer ends thereof against the insides of caps 11. Strip 12 comprises an inner layer 13 of insulating material, and two outer layers 14 of metal, preferably copper. Materials of this nature are known as metal clad laminates. The upper layer 14 of copper is subdivided by a transverse groove 19 into two separate sections. Bores 15 project transversely across strip 12 and a fine silver wire 16 is threaded through bores 15 and soldered at points 17 to the upper layer 14 of copper and at points 18 to the lower layer 14 of copper. The lower layer 14 of copper is subdivided by transverse grooves 19 into two axially outer sections and an axially inner section. The solder joints 18 connect wire 16 to said axially inner section of the lower layer 14. Solder joints 19' connect strip 12 to caps 11. As a result of the above construction of strip 12 the following current path is established through the fuse: left cap 11, left solder joint 19', upper copper layer 14, left solder joint 17, wire 16, left solder joint 18, lower copper layer 14, right solder joint 18, wire 16, right solder joint 17, upper copper layer 14, right solder joint 19', right cap 11. The above structure can be made to establish substantially the same thermal pattern as a fuse having a ribbon link with two serially connected necks or reduced cross-section portions of which each is sufficiently narrow and sufficiently short to approximate a point-heat-source when the fuse is carrying current. In a structure as shown in Figs. 3 and 4 the portions of wire 16 which are threaded through bores 15 form point-heat-sources when the fuse is carrying current, and the upper layer 14 and the lower layer 14 of copper form heat dissipating fins operating substantially in the same fashion as the portions of link 4 of Figs. 1 and 2 the cross-section of which is not reduced.

It appears from the foregoing that the structures of Figs. 1 and 2, on the one hand, and of Figs. 3 and 4, on the other hand, are, or may be made to be, in substance thermal equivalents of each other inasmuch as both comprise a conductor of electricity which has a drastically short portion of drastically reduced cross-section forming, or approximating, a point-heat-source when the fuse is carrying current. A closer approximation to a point-heat-source may be achieved by means of the structure of Figs. 3 and 4 than by means of the structure of Figs. 1 and 2 since the diameter of wire 16 may be as small as desired, whereas in the structure of Figs. 1 and 2 mechanical strength or dimensional stability considerations limit the minimum cross-sectional area which may be given to neck 7.

On occurrence of excessive loads the portions of the fine silver wire 16 situated inside bores 15 are destroyed by fusion and metal corrosion, and thus arcs are kindled inside of narrow bores 15 bounded by lateral walls of insulating material. As a result, arc quenching blasts are formed inside of bores 15. Since the lateral walls by which bores 15 are bounded are close to the arc paths, some of the insulating material of which layer 13 is made will evaporate under the heat of the arc. This greatly enhances the arc-extinguishing blast action of the structure. It will be apparent from the foregoing that one important difference between the structure of Figs. 1 and 2 and that of Figs. 3 and 4 consists in that there are no means in the former for establishing an arc quenching blast action, whereas the latter is provided with such means. The presence of arc quenching blast means tends to establish relatively high arc voltages.

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This may make it possible to dispense with an arc-quenching filler of quartz sand, as suggested by Figs. 3 and 4. Even if such a quartz filler were provided inside of casing 10 of the structure of Figs. 3 and 4, there would be little or no danger of formation of an arc-gap-shunting fulgurite upon fusion of silver wire 16 because the arc-extinguishing blasts rushing out of the end of bores 15 would keep particles of quartz sand in casing 10 away from the paths of the arcs formed inside of bores 15. It is thus apparent that the fuse structure of Figs. 3 and 4 differs radically from that of Figs. 1 and 2 in regard to arc-gap-shunting fulgurites.

The way in which fuses of the type shown in Figs. 3 and 4 are being manufactured is more fully disclosed in the co-pending patent application of Frederick J. Kozacka for Manufacturing Cartridge Fuses, filed December 11, 1956, Ser. No. 627,624.

Referring now to Fig. 5 which illustrates a three phase full wave rectifier, numerals 20 have been applied to indicate the three secondary Y-connected windings of a transformer used as a source of alternating current. This transformer is connected to a rectifier, and the automatic circuit interrupter or circuit breaker diagrammatically indicated at CB is interposed between the transformer and the rectifier. The rectifier comprises six rectifier cells 30, of which each is connected in series with a current-limiting fuse 31 of the type shown in Figs. 3 and 4. Reference numeral L has been applied to indicate the load in the D.-C. circuit of the rectifier. The automatic circuit interrupter or circuit breaker CB comprises three movable contacts 24, gang operated by means of cross-bar 26, each cooperating with one of the three fixed contacts 25. Spring 29 connected to cross-bar 26 biases the contacts 24 to the open position of the circuit interrupter. The transformer 20 and the circuit interrupter CB are connected to each other by conductors or leads 21 in each of which a tripping device 22 is arranged. Tripping devices 22 may be of any desired nature as long as they comply with the requirements set forth below. Reference character B in Fig. 6 indicates the tripping characteristic of an instantaneous electromagnetic tripping device 22. Each tripping device 22 is adapted to control the transverse trip bar 23. Trip bar 23 is, in turn, adapted to unlatch a latching mechanism 27, 28, latch 27 forming an integral part of cross-bar 26. If one of the tripping devices 22 responds to an excess current, trip bar 23 is actuated, thereby unlatching latch 27, 28 and thus permitting contacts 24 to move under the action of the bias of spring 29 to the open position thereof.

The link-destroying effect of certain low fusing point metals is generally used in the fuse art to establish time delays in the low overload range to preclude a fuse from blowing in response to harmless inrush currents of short duration as, for instance, inrush currents resulting from starting of electric motors. The time delay effect of certain low fusing point metals is achieved by a relative increase of the mass of a link and a concomitant increase of its heat absorbing capacity combined with the derating effect resulting from the application of a link-destroying low fusing point overlay. If the mass of a link is not increased and the link is provided with a critically thin overlay of a link-destroying low fusing point metal, a relative increase of speed of response may be achieved, i.e. under otherwise identical conditions the fuse may be caused to blow at an earlier point of time. This phenomenon may be explained as follows. If the neck of a ribbon link such as the neck 7 of the ribbon link 4 shown in Fig. 1 fuses on relatively high excess currents, i.e. currents which are so high as to cause fusion in times sufficiently short to permit neglecting heat exchange, this requires a predetermined $\int i^2 \cdot dt$. The limit conditions of this integral are the time at which current flow begins and the time at which the required latent heat of fusion has been supplied to neck 7. For this reason

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the above integral may be referred to as the fusion $\int i^2 \cdot dt$, which is a constant. Considering a fuse link with a relatively thin low fusing point metal overlay, the fusing point of the overlay will be reached much earlier than the fusing point of the base metal. Fusion of the overlay metal results in diffusion of the molecules of the base metal into the overlay metal and, therefore, in a corrosion of the base metal. The alloys formed between the base metal and the overlay metal have a relatively high resistivity, and therefore the resistance of the neck zone caused by the above corrosion process rises at a rapid rate. Considering a fault current which causes fusion of neck 7 within a time sufficiently short to minimize heat transfer phenomena away from neck 7, a condition can readily be visualized in which the actual fusing $\int i^2 \cdot dt$ of the necked link 4 with a thin low fusing point overlay thereon for destroying the link by a process in the nature of a chain reaction corrosion is less than the fusing $\int i^2 \cdot dt$ which would be required in the absence of said overlay. Thus the overlay is a means to boost rather than to delay the speed of response of neck 7 to excess currents.

All other parameters being equal the speed of response of a current-limiting fuse will increase with decreasing dimensions of the neck of the fuse link. A ribbon fuse link having a neck which forms virtually a point-heat-source must have a relatively large heat dissipating area immediately adjacent the neck to normally dissipate the relatively large amount of heat generated at the neck where the current density is very high. Only by providing a relatively large heat dissipating area immediately adjacent the neck can a given current-carrying capacity required for the link be achieved. In other words, the link must form a relatively wide cooling fin for its reduced cross-section portion or neck. The cooling and heat absorbing effect of the fin portion of a ribbon link which has a satisfactory fusing characteristic in the range of relatively high overcurrents tends to result in an undesirable time lag in the range of relatively low overcurrents. The aforementioned thin overlay of a link-destroying low fusing point metal tends to reduce the time delay in the low overcurrent range, yet for protection of very sensitive semiconductor rectifier cells, such as silicon rectifier cells, this reduction of the time delay inherent in a ribbon link with a point heat source forming neck is not sufficient. For certain applications, particularly protection of silicon rectifiers, the time lag in the low overcurrent range which is inherent in structures of the type shown in Figs. 1 to 4 is undesirable. Fig. 6 shows the fusing characteristic of the current-limiting fuses illustrated in Figs. 1 to 4 with a thin link-destroying low fusing point metal overlay on the point or points of reduced cross-sectional area. Reference letter D has been applied to this particular characteristic. Fig. 6 is intended to illustrate how the circuit breaker CB and the fuses 31 of Fig. 5 are coordinated. Since the R.M.S. current carried by each fuse 31 is

$$\frac{1}{\sqrt{2}}$$

the R.M.S. current carried by each tripping device 22, in drawing the fusing characteristic of Fig. 6 the values of the currents carried by each of fuses 31 were divided by $\sqrt{2}$ to permit plotting of the fusing characteristic in the same system of coordinates as the tripping characteristic of the current-limiting fuse is in the case of circuit breaker CB. It is apparent that the fuse-shape of a straight steep line. The rapid increase of its ordinates with decreasing overcurrents is but an analytical expression of the relatively long delay times in the range of relatively low overcurrents. To effectively protect the rectifier cells 30 in the range of low overcurrents the tripping means 22 of the circuit interrupter CB are adapted to trip the circuit interrupter in the low overload range within shorter times than the blowing or fusing times of the current-limiting fuses 31

as determined by the presence of the link-destroying low fusing point overlay on link 4, and more particularly on the neck portion 7 thereof, or as determined by such an overlay on wire 16 (see Figs. 3 and 4). To be more specific, tripping means 22 of circuit interrupter CB preclude blowing of any of current-limiting fuses 31 at inadmissible or dangerous over-currents less than 3 to 5 times the rated current of rectifier cells 30 and the rated current of current-limiting fuses 31. These currents, i.e. the current carried by any of cells 30 or fuses 31 are of the same order but may vary, say, for about 25%. The point of intersection between the fusing or blowing characteristic of the current-limiting fuses 31 and the tripping characteristic of the circuit interrupter is referred to as the cross-over point. Considering the protection of silicon rectifier cells, the cross-over point may be at about four times the current rating of cells 30 and of current-limiting fuses 31. In other words, the cross-over point is usually low compared with prior art applications of serially connected current-limiting fuses and automatic circuit interrupters or circuit breakers.

For the purpose of the foregoing considerations it is necessary to assume that all rectifier cells 30 and all current-limiting fuses 31 are virtually identical, and that the impedance of each current path including a rectifier cell 30 and a fuse 31 is identical so that the current flow in each of said current paths is equal. Actually this ideal condition can never be achieved. For this reason the fuses 31 might have a slightly higher current rating than the rectifier cells 30, the extreme speed of response of fuses 31 making up for any reasonable degree of over-fusing.

In addition to correcting the inherently slow speed of response in the region of small overloads of current-limiting fuses comprising fusible point-heat-source forming portions of reduced cross-sectional area and adjacent very effective heat dissipating means, the circuit interrupter CB offers the advantage of enabling rapid reclosing of the overloaded circuit subsequent to tripping of the circuit breaker CB on account of a temporary relatively small overload.

The reasons underlying the need for ultrarapid protection of germanium rectifier cells, on the one hand, and of silicon rectifier cells, on the other hand, are not exactly the same. The theory underlying ultrarapid protection of germanium rectifier cells has been set forth in considerable detail in the copending patent application of Kenneth W. Swain for Coordinated Static Power Rectifiers And Current-Limiting Fuses, filed June 13, 1955, Ser. No. 514,882, now United States Patent 2,921,250, issued January 12, 1960, and reference may be had to this patent for details on the subject of ultrarapid germanium rectifier cell protection. Regarding the protection of silicon rectifier cells, such cells can withstand much higher temperatures than germanium cells, yet they may reach their failure temperatures within a few microseconds. This is due to the fact that in such rectifier cells the current density per square inch of effective barrier layer area is very high, and the heat absorbing capacity of a silicon rectifier cell very small. Considering a silicon rectifier cell having a current rating of 15 amps. D-C. and 75 amps. of peak surge current, the total volume of such a cell may be in the order of .000227 cubic inch. Lack of any substantial mass capable of any significant heat absorption causes the temperature of silicon rectifier cells to rise very rapidly on occurrence of faults, particularly since the generation of heat is proportional to the second power of the fault current.

Referring again to Fig. 6, at the occurrence of current I in one of the tripping devices 22 will cause tripping of circuit breaker CB after an interval T. When tripping devices 22 carry I R.M.S. amps., fuses 31 carry a smaller current

which smaller R.M.S. current is sufficient to cause blowing thereof after the interval T. This is apparent from Fig. 6. It must be kept in mind when evaluating Fig. 6 that the ordinates of the blowing characteristic of the current-limiting fuse and of the tripping characteristic of the circuit interrupter are the same, whereas the abscissae of these two curves are different. At the cross-over point of both curves the time of response of both devices is equal, i.e. T seconds, but it takes the current I to trip the circuit breaker CB and the smaller current

$$I' = \frac{I}{\sqrt{2}}$$

to blow any of the fuses 31. In Fig. 6 I and I' are represented by lines of equal length, but both lines are drawn on different scales. The fusing characteristic of fuses 31 is determined by the overlay on the point of smallest cross-sectional area of their fusible element, i.e. on neck 7 or wire 16, respectively, and depends upon whether this overlay is made of tin, indium, or some other corrosive low fusing point metal, or any given alloy of such metals. Considering the protection of silicon rectifier cells, the cross-over point of the aforementioned characteristic ought to occur at 3 to 5 times the rated current of cells 30. In other words, I' ought to be 3 to 5 times, say, 4 times, the rated current of cells 30. The line C in Fig. 6 is the response characteristic of a fuse as shown in Figs. 1 to 4 with a fusible element of silver lacking any low fusing point metal overlay thereon.

The dotted rectifier cell damage curve A of Fig. 6 indicates the times during which a rectifier cell may carry predetermined excess currents without being damaged. This curve crosses the time-current-curve of the current-limiting fuses at the same point at which the time-current-curve of the current-limiting fuses is crossed by the tripping characteristic B of the automatic switch or circuit breaker CB. At this particular point the rectifier cells 30 may either be protected by the current-limiting fuses 31, or the automatic switch or circuit breaker CB. It is apparent from Fig. 6 that the current-limiting fuses 31 are not able to protect the rectifier cells 30 at currents less than I', in which case the circuit breaker CB takes over.

In a fuse structure such as illustrated in Figs. 1 and 2 intended for a current rating of 150 R.M.S. amps. the thickness of a ribbon link of silver may be .014", the width of the neck .020", and the length of the neck .031". Hence the cross-sectional area of that neck is .014" x .020". A neck of such large cross-sectional area can be rapidly destroyed by a layer of tin as thin as .001". Since the amount of silver present in the system is much larger than the amount of tin, or other link-destroying low fusing point metal, the silver will corrode sufficiently to saturate the liquid metal at the operating temperature. That amount of corrosion is sufficient to instantly increase the operating temperature by increased $I^2 \cdot r$ losses, resulting in increased corrosion, etc. The amount of corrosion of the silver neck may be sufficient to instantly raise the neck temperature to the fusion temperature of silver.

In a static system as the one under consideration, the amount of corrosion increases as the volume of the liquid metal increases. Any increase of the volume of the liquid metal is strictly limited since the resulting increase of heat absorbing capacity tends to slow down the metallurgical link-destroying reaction. The higher the temperature, the higher the solubility of the solid metal in the liquid metal, the higher the diffusion rates. For these reasons rapid neck destruction must be predicated upon high reaction temperatures rather than upon a large volume of low fusing point metal. The above explains the established fact that by appropriate choice of the thickness of the link-destroying low fusing point overlay metal the actual fusing $\int i^2 \cdot dt$ may be reduced below

$$\frac{I}{\sqrt{2}}$$

the fusing $i^2 \cdot dt$ required in the absence of the overlay.

From the above discussion it will be apparent that I have provided a coordinated system of current-limiting fuses and automatic circuit interrupters, or circuit-breakers, which is suitable for the protection of very critical rectifier cells whose successful protection may depend upon avoidance, in the excess current-range of more than 3-5 times cell rating, of time delays in the order of microseconds, and whose effective protection calls for also relatively speedy action in the range of relatively low excess currents, i.e. currents of less than 3-5 times cell rating. Considering in particular a silicon rectifier cell with a minimal heat absorbing capacity I have provided a protective system suitable for the protection of such a cell which system has a much higher overall speed of response than the speed of response that could be achieved heretofore.

While I have disclosed certain specific embodiments of my invention, it should be understood that my invention is not limited to the specific details and arrangement thereof herein illustrated, and I intend in the appended claims to cover all such changes and modification as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A protective system for rectifiers comprising a source of alternating current; a rectifier bridge including a plurality of substantially identical semiconductor rectifier cells each having a predetermined current rating connected to said source by leads to be supplied from said source; a plurality of substantially identical current-limiting fuses each connected in series with one of said plurality of rectifier cells, each of said plurality of current-limiting fuses comprising a fusible element having a reduced cross-section portion of silver sufficiently narrow and sufficiently short to approximate a point-heat-source when said element is carrying current, an element-destroying low-fusing-point metal overlay on said reduced cross-section portion sufficiently thin to reduce the actual fusing $i^2 \cdot dt$ thereof below the fusing $i^2 \cdot dt$ required for said element in the absence of said overlay and said current-limiting fuse further including blast action means operatively related to said point of reduced cross-section to preclude formation of an arc-gap-shunting fulgurite upon fusion of said point of reduced cross-section and inception of an arc; and an automatic circuit interrupter having separable contacts, said circuit interrupter being interposed in the leads of alternating current connecting said source to said bridge to control the flow of current from said source to said plurality of current-limiting fuses, and said circuit interrupter including tripping means adapted to trip said circuit interrupter when any of said plurality of cells and current-limiting fuses are carrying an inadmissible current less than 3 to 5 times said current rating within shorter times than the times required for said element-destroying low fusing point overlay to destroy said element by corrosive action in any of said plurality of current-limiting fuses.

2. A protective system for rectifiers comprising a source of alternating current; a rectifier cell supplied with current from said source and having a predetermined current rating; a current-limiting fuse arranged in series with said cell rated to continuously carry the same current as said cell; said current-limiting fuse including a pair of aligned spaced conductors having a relatively large cross-sectional area and defining a narrow gap therebetween at the juxtaposed ends thereof, a fusible conductive connection extending across said gap serially connecting said pair of conductors, said conductive connection having sufficiently small dimensions to approximate a point-heat-source when said pair of conductors is carrying current, an alloy-forming low-fusing-point overlay on said conductive connection adapted to reduce the actual fusing $i^2 \cdot dt$ on said conductive connection

below the fusing $i^2 \cdot dt$ required for said conductive connection in the absence of said overlay and wall means of insulating material arranged immediately adjacent said conductive connection adapted to form an arc-extinguishing blast upon fusion of said connection and kindling of an arc; and an automatic circuit interrupter having separable contacts arranged to disconnect said cell and said current-limiting fuse from said source of alternating current, said circuit interrupter having tripping means adapted to establish a tripping characteristic crossing over the blowing characteristic of said current-limiting fuse as determined by said overlay in such a way as to result in automatic opening of said circuit interrupter when said cell is carrying an inadmissible current between 3 and 5 times said current rating of said cell.

3. A protective system for rectifiers comprising a source of alternating current; a plurality of substantially identical semiconductor rectifier cells each having a predetermined current rating connected to be supplied by said source; a plurality of substantially identical current-limiting fuses having a predetermined current rating each arranged in series with one of said plurality of rectifier cells, each of said plurality of current-limiting fuses including a pair of aligned spaced conductors having a relatively large cross-sectional area and defining a narrow gap therebetween at juxtaposed ends thereof, a conductive connection of silver extending across said gap serially connecting said pair of conductors, said conductive connection having sufficiently small dimensions to approximate a point-heat-source when said pair of conductors is carrying current, an alloy-forming low-fusing-point overlay on said conductive connection adapted to reduce the actual fusing $i^2 \cdot dt$ of said conductive connection below the fusing $i^2 \cdot dt$ required for said conductive connection in the absence of said overlay, and wall means of insulating material arranged immediately adjacent said conductive connection adapted to form an arc-extinguishing blast upon fusion of said connection and kindling of an arc; and an automatic circuit interrupter with separable contacts interposed between said source and said plurality of current-limiting fuses, said circuit interrupter including tripping means establishing a sufficiently fast tripping characteristic to preclude blowing of any of said plurality of current-limiting fuses when carrying currents less than 3-5 times the rated current of each of said plurality of cells.

4. A protected semiconductor rectifier system comprising an A.-C. current supply; a semiconductor rectifier supplied with current from said supply and including a plurality of rectifier cells each having a predetermined current rating; a plurality of current-limiting fuses each arranged in series with one of said plurality of cells, each of said plurality of fuses including a pair of terminal elements, conductor means having a relatively large width conductively interconnecting said pair of terminal elements, said conductor means comprising a point of reduced cross-section sufficiently small to approximate a point-heat-source when said conductor means is carrying currents, a corrosive low fusing-point overlay adjacent said point of reduced cross-section adapted to reduce the actual fusing $i^2 \cdot dt$ of said point of reduced cross-section to a smaller value than the fusing $i^2 \cdot dt$ required for said point of reduced cross-section in the absence of said overlay, each of said plurality of fuses further comprising insulating means arranged in close proximity to said point of reduced cross-section closely confining the arc formed upon fusion of said point of reduced cross-section and defining passage means for the escape of products of arcing from said arc; an automatic circuit interrupter having separable contacts controlling the flow of current from said supply to said rectifier, and current responsive tripping means for said interrupter adapted to trip said interrupter on occurrence of overcurrents in said plurality of cells less than three times said current rating within shorter times than the fusing times at said overcurrents of said point of reduced cross-

section of said conductor means of each of said plurality of fuses.

5. A protected semiconductor rectifier system comprising a polyphase A.-C. current supply; a polyphase semiconductor rectifier supplied with current from said supply and including a plurality of rectifier cells each having a predetermined current rating; a plurality of current-limiting fuses each arranged in series with one of said plurality of cells, each of said plurality of fuses including a pair of terminal elements, conductor means having a relatively large width conductively interconnecting said pair of terminal elements, said conductor means comprising a point of reduced cross-section made of silver sufficiently small to approximate a point heat source when said conductor means is carrying current, a corrosive low fusing-point overlay adjacent said point of reduced cross-section adapted to reduce the actual fusing $\int i^2 \cdot dt$ of said point of reduced cross-section to a smaller value than the fusing $\int i^2 \cdot dt$ required for said point of reduced cross-section in the absence of said overlay, each of said current-limiting fuses further comprising insulating means defining an open passage housing said point of reduced cross-section and adapted to vent products of arcing formed upon fusion of said point of reduced cross-section; a multipolar automatic circuit interrupter having separable contacts controlling the flow of current from said supply to said rectifier, and a plurality of current responsive tripping means each in one phase of said polyphase supply each adapted to trip said interrupter on overcurrents in said plurality of cells less than three times said current rating with less time delay than the delayed blowing times of said plurality of fuses caused by the presence of said relatively large width of said conductor means.

6. A protective system comprising an electric circuit, a semiconductor rectifier cell having a predetermined current rating arranged in said circuit; a current-limiting fuse arranged in said circuit in series with said cell, said current-limiting fuse including a fusible element having a point of reduced cross-section sufficiently small to approximate a point-heat-source when said element is carrying current, a low-fusing-point overlay on said point of reduced cross-section adapted to reduce the actual fusing $\int i^2 \cdot dt$ required for said element below the fusing $\int i^2 \cdot dt$ required for said element in the absence of said overlay, and said current-limiting fuse further including blast action means operatively related to said point of reduced cross-section adapted to preclude formation of an arc-gap-shunting fulgurite upon fusion of said point of reduced cross-section and inception of an arc; and an automatic circuit interrupter having separable contacts arranged in said circuit with said cell and said current-limiting fuse, said circuit interrupter including tripping means adapted to trip said circuit interrupter at the occurrence of overload currents in said cell and said current-limiting fuse less than 3-5 times said current rating within shorter times than the blowing times of said current-limiting fuse as determined by the presence of said overlay on said fusible element.

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UNITED STATES PATENT OFFICE
CERTIFICATION OF CORRECTION

Patent No. 2,961,593

November 22, 1960

Frederick J. Kozacka

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 15, strike out all of the line preceding "ranges"; column 6, line 65, strike out "ing characteristic of the current-limiting fuse is in the" and insert the same after "that the fus-" in line 66, same column; column 10, line 49, for "plura ity" read -- plurality --; column 11, line 29, for "su ply" read -- supply --.

Signed and sealed this 23rd day of May 1961.

(SEAL)

Attest:

ERNEST W. SWIDER

Attesting Officer

DAVID L. LADD

Commissioner of Patents

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