

United States Patent

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[15] 3,646,400

[45] Feb. 29, 1972

[54] AIR-COOLING SYSTEM FOR HVDC VALVE WITH STAGGERED RECTIFIERS

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[22] Filed: Dec. 21, 1970

[21] Appl. No.: 99,893

[52] U.S. Cl. 317/100, 174/15 R, 321/8 C

[51] Int. Cl. H02b 1/18, H01b 7/34

[58] Field of Search 174/15 R, 16 R, DIG. 5;
321/8 C; 317/100, 234 A

[56] References Cited

UNITED STATES PATENTS

2,927,250 3/1960 Scharli 317/100

3,253,646 5/1966 Koltuniak 321/8 C
3,508,117 4/1970 Cuzner 317/100

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[57] ABSTRACT

Disclosed is a housing arrangement for a plurality of rectifier holding assemblies comprising a solid-state valve(s) of a high-voltage converter. The assemblies are mounted on panel structures which are disposed between sidewalls arranged parallel to and laterally offset from each other to form inlet ducts through which a cooling fluid may be brought to the assemblies and outlet ducts through which the cooling fluid from the assemblies exits. The cross-sectional area of the inlet and outlet duct portions adjacent the panel structures are such that the pressure drop in said portions are equal. Inlet and outlet ducts are mated together to decrease housing size.

7 Claims, 7 Drawing Figures

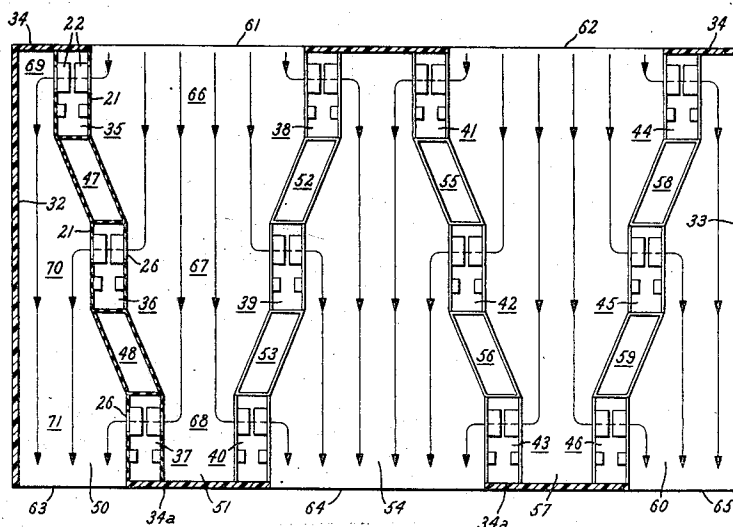


Fig. 1.

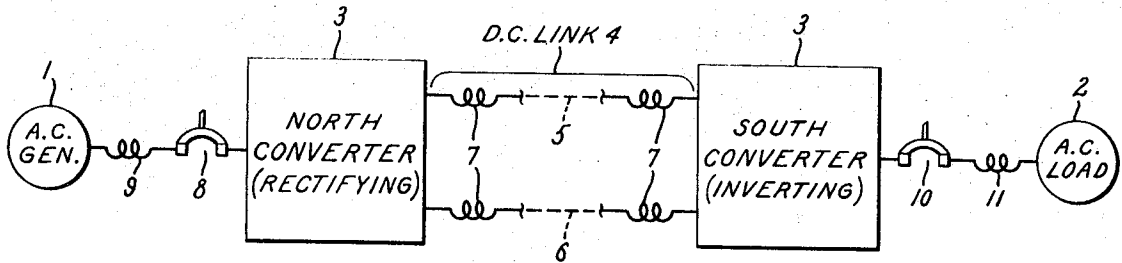


Fig. 2.

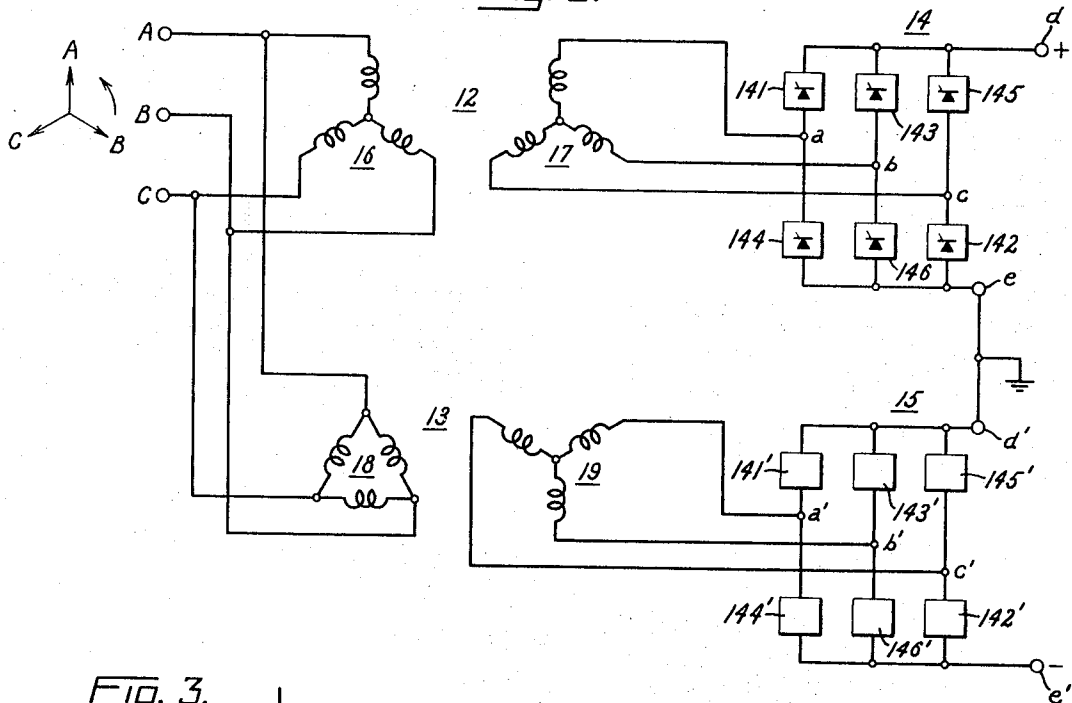
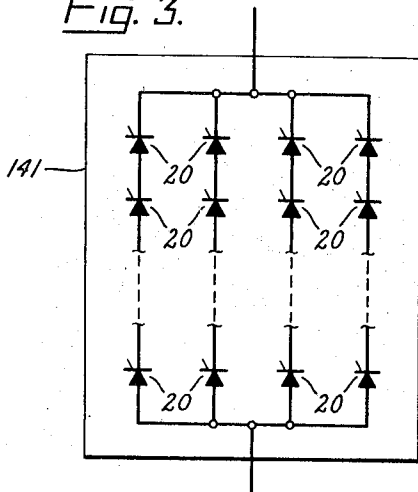


Fig. 3.



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Fig. 4.

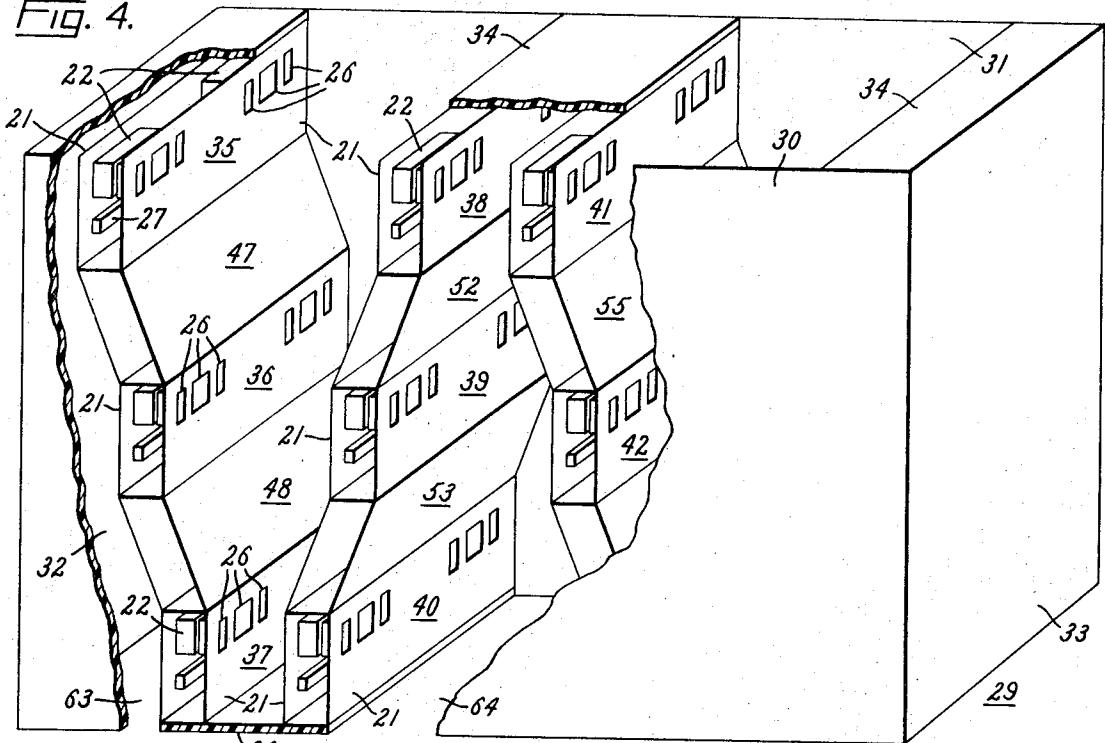
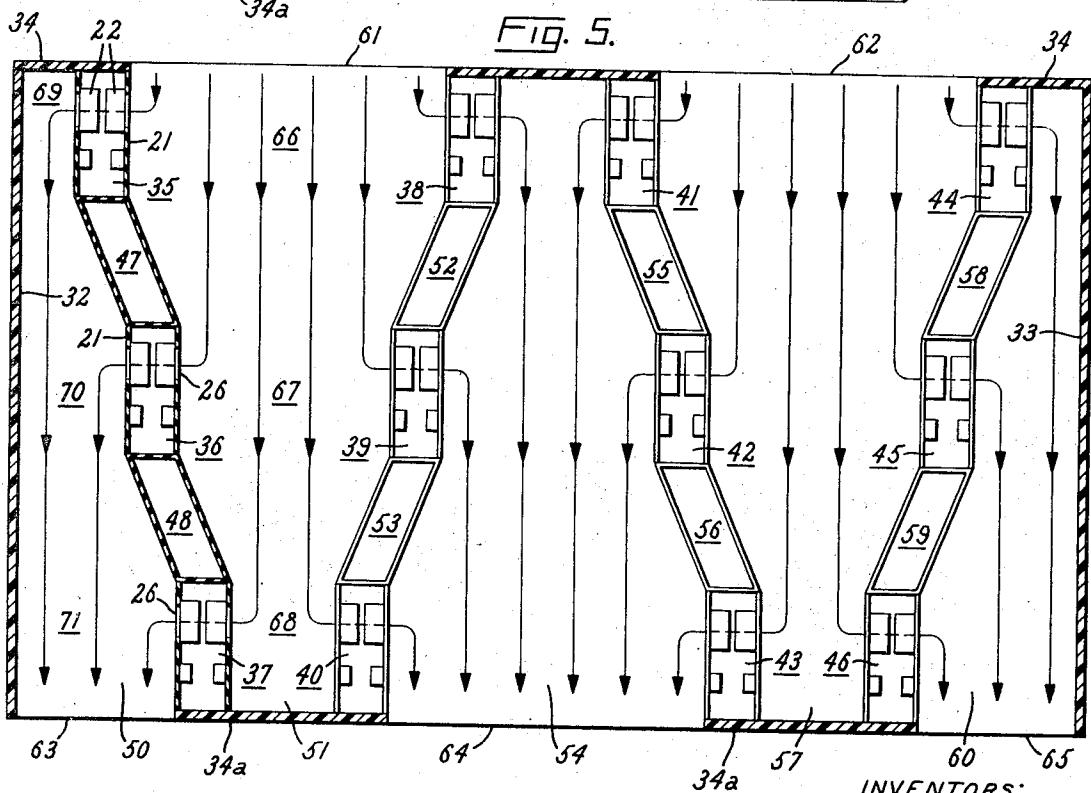


Fig. 5.



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Fig. 6.

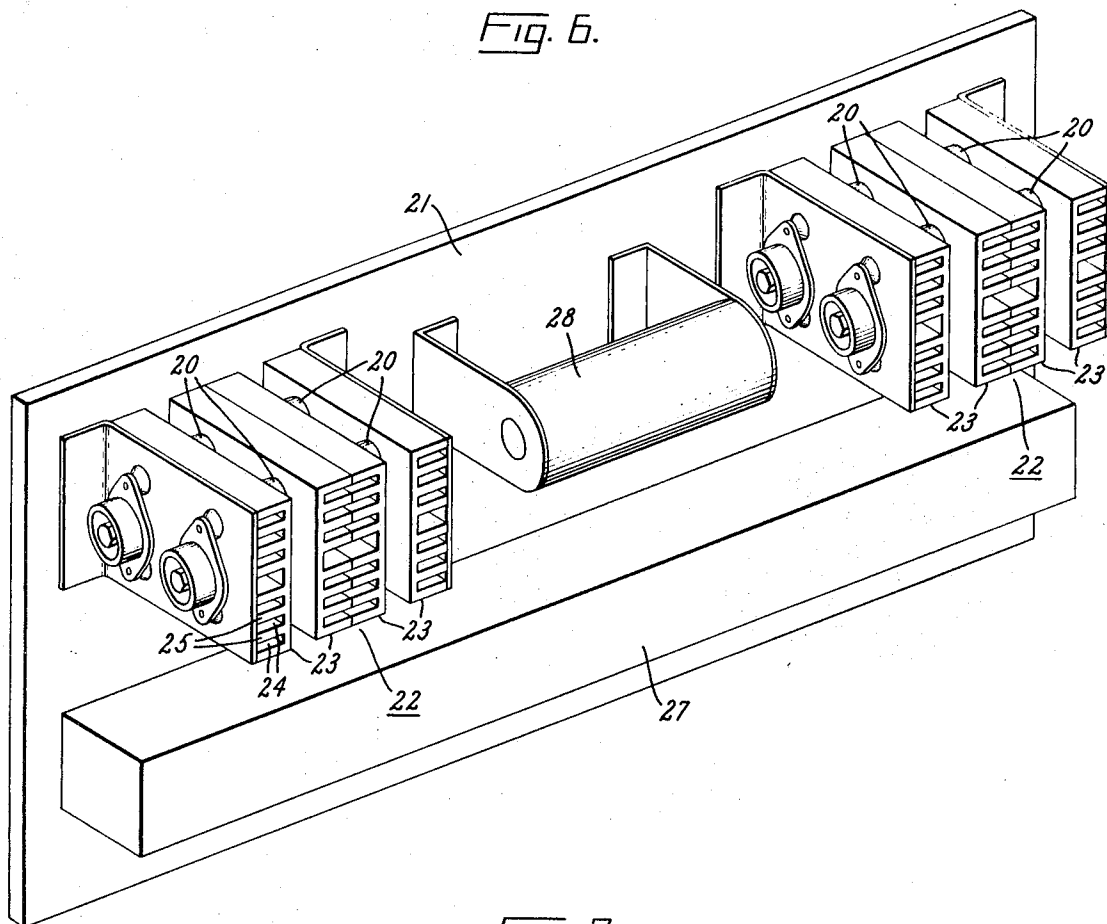
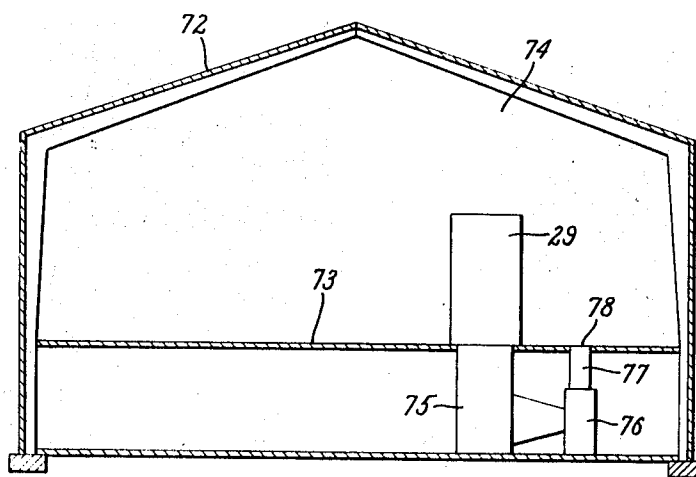


Fig. 7.



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AIR-COOLING SYSTEM FOR HVDC VALVE WITH STAGGERED RECTIFIERS

BACKGROUND AND OBJECTS OF THE INVENTION

This invention relates generally to a housing for a plurality of electrically interconnected, high-power semiconductor rectifiers held in a plurality of heat-dissipating assemblies and connected in a high-power electrical system, and more particularly it relates to a housing for mounting such heat-dissipating assemblies in an arrangement wherein each assembly and the rectifiers therein contained is adequately cooled by the flow of a cooling fluid through the housing.

Many applications have been proposed for high-power electrical apparatus comprising a plurality of high-current semiconductor rectifiers. For example, it is known that a plurality of silicon-controlled rectifiers, popularly referred to as thyristors, can be suitably combined and operated in series to form a unitary, controllable electric valve for use in high-voltage pulse modulators or in high-voltage switches. There is also a growing interest in using such valves in the AC/DC bridge circuits of high-voltage direct current (HVDC) electric power converters. Each of the individual rectifiers comprising such a valve is commonly constructed with a broad area semiconductor wafer, having at least one PN-rectifying junction, hermetically sealed in a housing including an insulating sleeve and a pair of conductive terminals which contact opposite sides of the wafer and cap the respective ends of the sleeve. Intimate contact can be maintained between the wafer and the terminal members of such rectifiers by the application of high pressure to the latter without utilizing solder or other bonding means.

In operation the passage of current through the rectifying junctions results in the generation of heat therein. Any contact resistance between the wafer and the terminals is another source of heat. Since the current-handling ability of a semiconductor rectifier is temperature limited, it is important to minimize the contact resistance while efficiently extracting the heat that is generated. Toward that end the rectifier may be sandwiched between opposing heat sinks which are clamped together by external spring means to apply high pressure evenly over the entire area of the interposed wafer to reduce contact resistance and to conduct heat away from the rectifier. For higher current ratings, an array of similarly poled rectifiers can be mounted in parallel between a single pair of heat sinks. Here it is particularly important to efficiently extract and radiate the rectifier-generated heat.

In copending application 48AV00273, assigned to the same assignee of our invention, there is disclosed novel heat-dissipating assemblies for mounting a parallel array of semiconductor rectifiers under pressure. Each assembly includes heat-dissipating electrodes for clamping the rectifiers therebetween and for extracting the heat which they generate during operation. To that latter end the electrodes include a plurality of narrow cooling fluid ducts, disposed immediately adjacent the rectifiers, through which a high-velocity turbulent cooling fluid is passed.

As disclosed therein such assemblies may be connected so that the rectifiers mounted in one assembly are in electrical series with those in other similar assemblies to form a high-voltage valve suitable for connection with other such valves to form a bridge circuit for an HVDC system.

In order for all of the rectifiers mounted in the assemblies to perform efficiently, they should be operated in an ambient temperature controlled within a specific range. To that end the assemblies may be mechanically supported and electrically interconnected inside a housing through which a cooling fluid is circulated to extract the rectifier-generated heat. A variety of physical arrangements for such housings have heretofore been suggested in the pertinent art, but insofar as we are now aware they are all, as a practical matter, less than the optimum desired for our present purposes.

Our general design goals are to reduce the volume of the housing, to improve the accessibility of the assemblies mounted therein, and to promote equal cooling of the in-

dividual rectifier components. Reducing the size of the housing is desirable because of the savings in initial construction costs and in the size and costs of the building where the housing will be finally installed. Accessibility is desired for reducing the time and the expense associated with the maintenance and the servicing of the apparatus.

In the interests of operating reliability, cooling efficiency, and economy, each of the rectifier-holding assemblies in a single housing should be cooled equally, with none receiving more or less than its proportional share of the cooling fluid. If one of the assemblies tended to receive less than its proportional share of the cooling fluid, additional or lower temperature cooling fluid would have to be supplied into the housing to prevent overheating of that one assembly. This may necessitate the use of any or all of the following: larger inlet and outlet ducts, a larger housing therefore, more or larger fluid-moving devices, and a lower temperature cooling fluid. Furthermore, it may be accompanied by preferential cooling of some of the assemblies which will consequently operate at lower temperature than desired thereby resulting in a current imbalance.

It is therefore an object of our invention to provide a compact housing in which a plurality of removable heat dissipating-rectifier holding assemblies are arranged so that all of the assemblies are exposed to substantially equal quantities of a cooling fluid passing through the housing.

It is a further object of our invention to provide a relatively small housing in which a plurality of heat-dissipating, rectifier-holding assemblies are arranged so that each is substantially equally cooled by the passage of cooling fluid through the housing.

SUMMARY OF THE INVENTION

In carrying out our invention in one form, a housing is provided for mounting a plurality of panel structures, upon which a plurality of heat-dissipating, rectifier-holding assemblies are disposed, in an arrangement wherein each assembly receives a substantially equal share of a cooling fluid which is introduced into the housing.

The housing includes sidewalls which enclose the panel structures and which together therewith form cooling fluid ducts disposed on opposite sides of those panel structures with portions thereof adjacent thereto. An inlet aperture is provided in the housing for permitting the cooling fluid to enter one of the housing ducts, hereinafter called the inlet duct. The inlet duct is provided for carrying the cooling fluid to the panel-mounted, heat-dissipating assemblies. Another of the housing ducts, hereinafter referred to as an outlet duct, is provided for carrying the cooling fluid away from those assemblies. The outlet duct communicates with an outlet aperture in the housing for allowing the cooling fluid to exit the housing.

The panel structures are provided with apertures therein which permit cooling fluid to pass from the inlet duct through the heat-dissipating assemblies to the outlet duct. The panel structures are arranged parallel to and laterally offset from each other so that the inlet duct decreases in cross-sectional area in the direction of the fluid flow and the outlet duct increases in cross-sectional area in that direction. The cross-sectional area of the inlet duct portion adjacent each panel structure is such that the pressure drop in said portions are approximately equal. Similarly the cross-sectional area of the outlet duct adjacent any panel structure is such that the pressure drop in said portions are approximately equal. Such a configuration enables each heat-dissipating assembly to receive a substantially equal share of the cooling fluid which is introduced into the housing.

The inlet and outlet ducts are disposed so that large cross-sectional area portions of the inlet duct mate with small cross-sectional area portions of the outlet duct and vice versa so that the total volume taken up by the ducts is minimized and a relatively small housing provided.

BRIEF DESCRIPTION OF THE DRAWINGS

Our invention will be better understood and its various objects and advantages will be more fully appreciated from the following description taken in conjunction with the accompanying drawings in which:

FIG. 1 is a schematic one line diagram of a typical HVDC system in which our invention can be advantageously used.

FIG. 2 is a schematic circuit of the North converter shown in FIG. 1.

FIG. 3 is a schematic circuit diagram of a typical valve in the converter shown in FIG. 2.

FIG. 4 is a perspective view partially broken away of a housing in accordance with our invention.

FIG. 5 is a front view of the housing shown in FIG. 4.

FIG. 6 is a perspective view of a panel board for mounting a plurality of rectifier-holding, heat-dissipating assemblies in our housing.

FIG. 7 is a front view in section of a building enclosing our housing and associated cooling equipment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Some of the features shown and described herein from the subject of other copending patent applications (48AV00273 and 48AV00357) assigned to the same assignee as our invention.

Insofar as our invention is concerned, FIG. 1 is a one-line representation of a source 1 ("A-C Gen.") supplying electricity to a load 2 ("A-C Load") via a DC system comprising a pair of high-voltage converter plants 3 interconnected by a DC link 4. The link 4 comprises a nominally positive DC conductor 5 paralleled by a relatively negative DC conductor 6, each conductor having smoothing chokes or reactors 7 in series therewith. The converter at the source terminal of the transmission line is called "North Converter (rectifying)." Its AC side is coupled to the source 1 by means of a circuit breaker 8, and the AC system impedance is symbolically shown at 9. The converter at the opposite terminal of the transmission line is called "South Converter (inverting)," and its AC side is coupled to the load 2 by way of another circuit breaker 10 and AC system impedance 11.

In practice the electric power system shown in FIG. 1 could be bidirectional. For example, an additional source of power could be coupled to the AC network fed by the South converter for supplying, on demand, other loads coupled to the AC side of the North converter. The direction of power in the DC transmission line is readily reversed by changing the operating modes of the converters at the respective terminals so that the South one acts as a rectifier and the North one acts as an inverter.

FIG. 2 is a schematic circuit diagram of the North converter 3 of the FIG. 1 system. It will be observed that this converter comprises first and second power transformers 12 and 13 in combination with first and second AC/DC bridges 14 and 15 respectively. The first transformer 12 has two inductively coupled sets 16 and 17, of three star-connected windings. The windings of one set 16 are connected respectively to three separate terminals A, B, and C which in turn are adapted to be connected to the respective phases of a three-phase AC electric power system whose phase rotation is A, B, C. The windings of the companion set 17 are respectively connected to AC terminals *a*, *b*, and *c* of the first bridge 14. The bridge 14 has a pair of DC terminals *d* and *e*, with the former being connected to the positive DC terminal of the illustrated converter and the latter being connected to ground.

The second transformer 13 of the North converter comprises a set 18 of three delta-connected windings inductively coupled to a set 19 of three star-connected windings. The windings of the set 18 are respectively connected to the three terminals A, B, and C, while the windings of the companion set 19 are respectively connected to the AC terminals *a'*, *b'*

and *c'* of the second bridge 15. With this arrangement, the AC voltages at the latter terminals will lag those at the corresponding terminals *a*, *b*, and *c* of the first bridge 14 by a phase angle of 30 electrical degrees. The bridge 15 has a pair of DC terminals *d'* and *e'*, the former being connected to ground and the latter being connected to the negative terminal of the illustrated converter. Thus the two bridges 14 and 15 are connected in series with one another between the positive and negative terminals of the converter, and the DC voltage across these terminals is the sum of the outputs of the respective bridges.

Bridge 14 comprises six identical controlled valves 141, 142, 143, 144, 145 and 146 arranged in a three-phase double-way six-pulse configuration. Thus the cathodes of the odd-numbered valves are connected in common to the upper DC terminal *d* of the bridge, and the anodes of the even-numbered valves are connected in common to the other DC terminal *e*. The anode of the valve 141 and the cathode of valve 144 are both connected to the first terminal *a* of the three-phase AC terminals of the bridge. The anode of valve 143 and the cathode of valve 146 are both connected to the second AC terminal *b*. The anode of valve 145 and the cathode of valve 142 are both connected to the third AC terminal *c*. By firing these six valves in their numbered sequence at intervals of 60 electrical degrees, three-phase electric power supplied to the AC terminals of the bridge can be converted to DC power.

Bridge 15 is composed of valves 141', 142', 143', 144', 145' and 146' whose arrangement and operation are similar to the valves of bridge 14. The gate pulses for sequentially firing the valves of bridge 15 will be interleaved with the gate pulse for the correspondingly numbered valves in the leading bridge 14, thereby forming a 12-pulse converter.

The average magnitude of the rectified voltage between the DC terminals *d* and *e'* is maximum when the firing angle of these gate pulses is zero. By increasing the firing angle to nearly 90°, the DC voltage can be reduced to zero. Still greater firing angles are used when the bridge is operating in its inverting mode, at which time the potential of terminal *d* is negative with respect to terminal *e'* and DC electric power supplied to these terminals is converted to three-phase AC power.

The DC voltage rating of either bridge depends on the individual voltage rating of each valve. FIG. 3 shows the construction of valve 141. This valve, like all the others, comprises a plurality of semiconductor rectifier devices 20. The rectifiers 20 are connected in parallel arrays for high current handling capacity, and a plurality of these arrays are connected in series for high voltage handling capacity. Although rectifiers 20 are shown schematically as thyristors (i.e., controlled rectifiers) it should be apparent that other rectifier types (e.g., diodes) may be used, depending upon the function to be performed.

In a HVDC system each valve making up the converter may include, as for example, a series string of 50 arrays of four parallel thyristors each. In FIG. 4 of the above noted copending application there is shown a heat-dissipating, rectifier-holding assembly for mounting two thyristors in series in each of four parallel paths. A plurality of such assemblies may be mounted on panel structures and electrically interconnected to form a converter valve like that discussed above.

Either a single valve so constructed, or a plurality of such valves may be disposed in a unitary cooling housing constructed in accordance with our invention. As disclosed and claimed in copending application 48AV00357, assigned to the same assignee as our invention, at least one valve pair of one of the serially connected bridges 14 and 15 and a valve pair of the other of those bridges may be disposed in our unitary cooling housing in order to minimize the amount of electrical insulation and space required for the entire converter apparatus. In any event our invention contemplates disposing a plurality of semiconductor rectifier-holding, heat dissipating assemblies in a housing which is arranged to insure that all of the rectifiers are cooled equally. The electrical connection between the rectifiers in our housing can be made as desired.

In FIG. 3 there is shown a panel board 21 which is adapted for disposition along with like panel boards in our inventive housing. Mounting upon panel board 21 are a pair of heat dissipating, rectifier holding assemblies 22. Although these assemblies can take other suitable forms, they are particularly shown as being the same as FIG. 4 of the first-mentioned copending application. Each assembly includes plural heat-dissipating electrodes 23 which electrically contact respective terminals of the rectifiers 20 to apply pressure to them and extract the heat which they generate in operation. To the latter end a plurality of narrow cooling fluid ducts 24 are provided in the electrodes 23. These ducts are formed by a plurality of heat-dissipating fins 25 and are disposed immediately adjacent the rectifiers. The ducts are narrow so that upon the passage of a high-velocity cooling fluid therethrough, turbulence results which effectuates efficient heat extraction. Inasmuch as the ducts are narrow, a large pressure drop will result in those ducts when cooling fluid flows therethrough. The advantage of use of a high pressure drop assembly in our housing will be considered later.

Each of the assemblies 22 are directly mounted on panel boards 21 so that the cooling ducts 24 in electrodes 23 communicate with apertures 26 in the panel boards. These apertures can be seen in FIG. 4. Panel board 21 also serves to mount gate pulse forming circuitry 27 for the rectifiers and a saturable core reactor 28 in series with the rectifiers as well as protective circuitry (not shown) for the rectifiers. More information about the details and operation of some of these circuits can be found in U.S. Pat. No. 3,424,664 (Dewey). Panel board 21 is made of an electrical insulating material to prevent the rectifiers from being short circuited since electrodes 23 are mounted directly to the panel board.

FIG. 4 is a perspective view, partially broken away, of a cooling housing constructed in accordance with our invention. Housing 29 comprises a pair of sidewalls 30 and 31, a pair of end walls 32 and 33, a top wall 34, and a bottom wall 34a. Disposed inside the housing are a plurality of panel boards 21 like that shown in FIG. 6. Each panel board is adapted for easy removal from the housing. Toward that end the housing may include openings in the sidewalls through which the panels may be passed for insertion in or removal from the housing. To expedite their insertion or removal the panels may be adapted for sliding on tracks provided inside the housing normal to the sidewalls. Cover plates may be provided for sealing the sidewalls openings.

As shown in FIG. 5 the panel boards are disposed in pairs which are parallel to and closely spaced apart from each other so that their apertures 26 are aligned. Each pair forms a separate panel structure, namely 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45 and 46. Although the panel structures are shown as including two panel boards 21, panel structures including more or less than two panel boards can also be utilized. The reason for the use of the two board panel structures shown will be considered later.

As can be seen from FIG. 4 and 5 an insulating member 47 is connected between panel structures 35 and 36 and an insulating member 48 is connected between panel structures 36 and 37. Panel structures 35, 36 and 37 and members 47 and 48, as a group, form a wall of a pair of ducts 50 and 51. An insulating member 52 is connected between panel structures 38 and 39 and an insulating member 53 is connected between panel structures 39 and 40. Panel structures 38, 39 and 40 and members 52 and 53, as a group, form another wall of duct 51 and a wall of another duct 54. An insulating member 55 is connected between panel structures 41 and 42 and an insulating member 56 is connected between panel structures 42 and 43. Panel structures 41, 42 and 43 and insulating members 55 and 56, as a group, form another wall of duct 54 and wall of another duct 57. An insulating member 58 is connected between panel structures 44 and 45 and an insulating member 59 is connected between panel structures 45 and 46. Panel structures 44, 45 and 46 and insulating members 58 and 59, as a group, form another wall of duct 57 and a wall of another duct 60.

The function of ducts 51 and 57, hereinafter called inlet ducts, is to carry a cooling fluid to the panel structures in the housing so that it can extract the rectifier-generated heat from the panel-mounted assemblies. The function of ducts 50, 54 and 60, hereinafter called the outlet ducts, is to provide a passage through which the fluid can pass after having extracted the rectifier-generated heat.

The top wall 34 of housing 29 includes a pair of apertures 61 and 62. Aperture 61 communicates with duct 51 and aperture 62 communicates with duct 57. These apertures are provided to permit the ingress of the cooling fluid into their associated housing ducts and are denoted as entrance apertures. The bottom wall 34a of the housing includes three apertures 63, 64 and 65. Aperture 63 communicates with duct 50, aperture 64 communicates with duct 54 and aperture 65 communicates with duct 60. These apertures are provided to permit the fluid to exit the housing and are denoted as exit apertures.

The path of the fluid flow through the housing is schematically illustrated by the arrowheaded lines shown in FIG. 5. As can be seen therein the fluid enters housing 29 through entrance apertures 61 and 62. Once in the housing it is channeled into respective inlet ducts 51 and 57, through which it flows to the panel structures forming the walls thereof. From there it passes through panel apertures 26 and enters the narrow cooling ducts 24 of the panel-mounted assemblies 22. In its passage through these ducts it extracts the rectifier-generated heat so that its temperature is necessarily increased. Upon exiting ducts 24 the elevated temperature fluid passes through respective outlet ducts 50, 54 and 60, and corresponding exit apertures 63, 64 and 65 to exit the housing.

As was previously noted it is desirable to minimize the housing size while insuring that each heat-dissipating assembly and the rectifiers mounted therein receives its fair share of cooling fluid. Therefore the panel structures are arranged to form particularly configured cooling ducts which effectuate those ends. As can be seen from FIGS. 4 and 5 the panel structures are arranged parallel to each other but laterally offset therefrom so that the inlet ducts decrease in cross-sectional area in the direction of the fluid flow while the outlet ducts increase in cross-sectional area in that direction. For example, panel structure 36 is parallel to and laterally offset from panel structure 35 while panel structure 37 is parallel to and laterally offset from panel structure 36. Similarly, panel structure 39 is parallel to and laterally offset from panel structure 38 while panel structure 40 is parallel to and laterally offset from panel structure 39. When arranged in this manner the cross-sectional area of the portion 66 of inlet duct 51 located between panel structures 35 and 38 is larger than the cross-sectional area of the duct portion 67 located between panel structures 36 and 39 and the cross-sectional area of duct portion 67 is larger than the cross sectional area of the duct portion 68 located between panel structures 37 and 40. Further, the cross-sectional area of the portion 69 of outlet duct 50 located between sidewall 32 and panel structure 35 is smaller than the cross-sectional area of duct portion 70 located between the sidewall and panel structure 36 and the cross-sectional area of the latter duct portion is smaller than the cross-sectional area of the duct portion 71 located between the sidewall and panel structure 35.

As was previously noted the arrowheaded lines in FIG. 5 represent the path of the cooling fluid through the housing 29. Each line also represents a unit amount of fluid necessary to adequately cool the rectifiers mounted in the assemblies on one panel structure.

If the pressure drop along each path through the housing is approximately equal, the amount of fluid flowing in each path will also be approximately equal and each rectifier will receive a substantially equal share of the cooling fluid. Assemblies 22 are constructed to such close tolerances that the pressure drop through the ducts 24 in any one of them will be the same at any given fluid flow as the pressure drop through the ducts of another. The inlet and outlet ducts are configured so that pressure drop in each duct portion is approximately equal, whereby the total pressure drop along each path will be ap-

proximately equal and efficient cooling of all rectifiers is obtained.

As can be seen from FIG. 5 six units of cooling fluid are brought through entrance aperture 61 into inlet duct 51 for cooling the rectifiers mounted on the six panel structures 35-40 forming walls of that duct. Similarly six units are brought through entrance aperture 62 into inlet duct 57 for cooling the rectifiers mounted on the six panel structures 41-46 forming walls of that duct. For the sake of brevity only the cooling of the rectifiers in panel structures 35-40 will be discussed since the cooling of the rectifiers in panel structures 41-46 occurs in a similar manner.

In portion 66 of inlet duct 51 one of the six units of cooling fluid will enter the cooling ducts 24 in the assemblies 22 mounted on panel structure 35. A second one of the six units of fluid will enter the cooling ducts in the assemblies mounted on panel structures 38. Accordingly, only four units of fluid remain in inlet duct 51 to pass into duct portion 67. If the cross-sectional area of that portion were not reduced with respect to that of duct portion 66, the pressure drop in it would be less than the pressure drop in portion 66 since there is less fluid in it (i.e., four units of fluid) than in portion 66. Similarly, if duct portion 68 were not further reduced in cross-sectional area, the pressure drop in it would be less than in portion 67, since another unit of fluid enters the cooling ducts 24 in the assemblies mounted on panel structure 36 and yet another unit enters the ducts 324 in the assemblies mounted on panel structure 39, thus leaving only two units in duct portion 68. By making the cross-sectional area of inlet duct portion 67 proportionally smaller than that of duct portion 66 and the cross-sectional area of duct portion 68 proportionally smaller than that of duct portion 67, we ensure that the pressure drop in each duct portion is approximately equal.

Insofar as outlet duct 50 is concerned it should be noted that the unit of fluid passing through the assemblies on panel structure 35 will enter duct portion 69, pass therethrough and enter duct portion 70. The unit of fluid passing through the assemblies on panel structure 36 will also enter duct portion 70. Therefore there will be a total of two units of fluid disposed therein. If duct portion 70 were not enlarged in cross-sectional area compared to duct portion 69, the pressure drop in it would be higher than in duct portion 69 due to the two units of cooling fluid therein. As can be seen in FIG. 5, we have made the cross-sectional area of duct portion 70 proportionately larger than that of portion 69, and similarly the cross sectional area of duct portion 71 is made proportionally larger than that of duct portion 70. Therefore the pressure drop in each portion of the outlet duct 50 is approximately equal.

It should be noted that of the 6 units of fluid entering inlet duct 51, only three units exit through outlet duct 50. The other three units (i.e., the units which serve the rectifiers in panel structures 38-40) exit through outlet duct 54. The three units of fluid used for cooling the rectifiers in panel structures 41, 42 and 43 also exit through duct 54. The duct 54 is configured so that the pressure drop in each of its portions is also approximately equal.

Although the arrangement of panel structures in housing 29 provides substantially equal pressure drops in each portion of the inlet and outlet ducts adjacent those panels, some variation in the pressure drop in different portions can be tolerated if the pressure drop through the rectifier-holding assemblies is significantly higher than the pressure drop in those duct portions. For example, if the pressure drop through ducts 24 of each of the assemblies 22 is 3 inches of water and the pressure drop in most of the inlet and outlet duct portions is 0.05 inches of water it will make little difference, insofar as equal distribution of cooling fluid is concerned, if the pressure drops in the remaining duct portions are 0.06 inches of water. In the preferred embodiment shown herein the pressure drop through ducts 24 is at least two orders of magnitude higher than the pressure drop through the inlet and outlet duct portions inasmuch as ducts 24 are much narrower than inlet ducts 51 and 57 and outlet ducts 50, 54 and 60. In situations where

the difference between the pressure drop through the assemblies and the inlet and outlet ducts is not as great, our duct configuration, in ensuring the existence of equal duct pressure drops, takes on added significance in enabling the rectifiers mounted in the assemblies to receive an equal share of cooling fluid.

In any event our inlet and outlet duct arrangement enables the construction of a smaller housing for cooling the same number of assembly-mounted rectifiers than one utilizing constant cross-sectional area inlet and outlet ducts. By virtue of the fact that our housing panel structures are disposed parallel to and laterally offset from each other, the inlet and outlet ducts disposed on either side thereof are in effect mated together, with the inlet duct portions of large cross-sectional area adjacent the outlet duct portions of small cross-sectional area and vice versa. In order to provide the same amount of cooling fluid to the rectifiers in a housing utilizing constant cross-sectional area ducts as is provided in our housing, its inlet duct would have to be of the same cross-sectional area as our inlet duct at the entrance aperture and its outlet duct would have to be of the same cross-sectional area as our outlet duct at the exit aperture. Since our inlet and outlet ducts are of decreased cross-sectional area at portions remote from those apertures the volume which each of our ducts enclose is necessarily less than the volume enclosed by the corresponding constant cross-sectional area duct. Accordingly, when our ducts are mated as shown and described, the volume which our housing must enclose is less than the volume to be enclosed with the constant cross-sectional area ducts. Reducing the size of a housing without reducing the amount of cooling fluid is economically desirable.

FIG. 7 shows a building or valve hall 72 in which our housing may be disposed for use with air as the cooling fluid. The cooling system shown therein is of the two plenum, closed-loop, forced-air type. As can be seen, building 72 includes a floor 73, upon which one or a plurality of our housings 29 can be disposed. The airspace 74 above the building floor acts as one plenum while the enclosed space 75 below the floor acts as the second plenum. The first plenum communicates with the inlet ducts 51 and 57 inside the housing 29 via entrance apertures 61 and 62. The second plenum communicates with the outlet ducts 50, 54 and 60 inside the housing via exit apertures 63, 64 and 65.

A plurality of fans 76, only one of which can be seen, are disposed below the floor 73 and communicate with the plenum 75 to draw the air from the upper plenum 74 through the housing ducts and the heat-dissipating assemblies into the lower plenum 75. From this lower plenum, the air, which was heated in extracting heat from the rectifiers, is forced through an air-to-glycol heat exchanger 77 whereupon the temperature of the air is reduced to a predetermined temperature (depending upon the amount of rectifier-heat to be extracted). The cooled air is then returned to the upper plenum via apertures 78 (only one of which can be seen) in floor 73.

The upper plenum, being the interior of building 72, is large enough to be considered as an infinite air source. Thus air turbulence is minimal at the housing entrance apertures so that each housing inlet duct receives the same amount of air as any other inlet duct. Similarly, the lower plenum 75 is made large enough so that air turbulence therein is minimized whereupon each fan can act upon an equal amount of air with no one fan working harder or easier than others.

In the interest of economy the panel structures in our housing are made up of a pair of panel boards 21 upon which plural heat dissipating assemblies 22 are mounted. The boards of each pair are arranged such that the cooling air which passes through the cooling fluid ducts in the assemblies on one board of the pair also passes through the cooling fluid ducts in the assemblies on the other board of the pair before entering the outlet duct. With such an arrangement only half as much air is needed to cool the rectifiers in the housing as would be necessary in the panel structures included only one panel board, since each unit of air is used to cool two assemblies before ex-

iting the housing. It should be apparent that with this arrangement the number of fans can be reduced. However, more power will be necessary to drive the fans used due to the increased pressure drop through the housing resulting from the double panel board arrangement. The advantage of using plural panel board structures in our housing can best be appreciated by comparing three exemplary housings constructed in accordance with our invention, namely, housings A, B, and C.

Housing A shall be assumed to utilize single panel board structures with 12,000 cubic feet of air per minute required to cool the rectifiers contained therein. Further, it shall be assumed that the pressure drop through assemblies 22 used therein is 3.5 inches of water and the housing's inlet and outlet ducts are of such cross-sectional area that the total pressure drop therethrough is 0.2 inches of water. Thus the total pressure drop through the housing A is 3.7 inches of water.

Housing B shall be assumed to be identical to housing A except that the panel structures each comprise a pair of panel boards as shown in FIGS. 4 and 5. Since the same air that cools one panel of the pair also cools the other panel of the pair only half as much air (i.e., 6,000 c.f.m.) has to be supplied into housing 29. Accordingly, only half the number of fans are needed with housing B as with housing A. Owing to the fact that the same air will pass through the cooling ducts in two assemblies the total pressure drop therethrough is up to approximately twice the pressure drop through one assembly (e.g., 7 inches of water). But since only 6,000 cubic feet of air per minute is passed through the inlet and outlet ducts the total pressure drop therein is only 0.1 inches of water. Thus the total pressure drop through housing B is 7.1 inches of water. This increased pressure situation requires additional power to effectively drive the air through the housing. Thus when using housing B the number of fans can be reduced in half but the power required to drive those fans would be greater, although not quite double.

Housing C shall be assumed to be arranged like housing B but with narrower inlet and outlet ducts so that the 6,000 cubic feet of air per minute passing therethrough results in a total pressure drop therein of 0.2 inches of water (the same as in housing A). The total pressure drop through housing C is thus 7.2 inches of water. It should be appreciated that housing C, like housing B, although requiring half the number of fans as would housing A nevertheless requires more power to DRIVE them. In fact the power required to drive the fans supplying housing C is slightly more than that needed for housing B since the total pressure drop therein is slightly more (i.e., 0.1 inch of water). However, the space saving in making the inlet and outlet ducts narrower should make up for the additional power required.

While we have shown the panel structures as including a pair of panel boards 21 it should be apparent that any number of panel boards can be used, providing the temperature of the air is low enough to ensure effective cooling of all the assemblies through which the air passes.

While we have shown and described a particular embodiment of our invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from our invention in its broader aspects; and we, therefore, intend herein to cover all such changes and modifications as fall within the true spirit and scope of our invention.

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

1. In high-voltage electrical apparatus composed of a plurality of semiconductor rectifiers held in heat-dissipating as-

semblies mounted on supporting panel structures in a housing, said housing having sidewalls enclosing said panel structures and having entrance and exit apertures for the ingress and egress of cooling fluid to the housing, the improvement comprising: means mounting selected panel structures in an arrangement which forms walls of a pair of ducts in said housing through which the cooling fluid is made to flow, said ducts being disposed on opposite sides of said panel structures with portions thereof adjacent thereto, a first one of said ducts communicating with said entrance aperture for carrying the cooling fluid to the mounted assemblies, the other of said ducts communicating with said exit aperture for carrying said fluid away from said assemblies, said panel structures being disposed generally parallel to and laterally offset from each other so that the portion of the first duct adjacent one panel structure has a smaller cross sectional area than the portion of the same duct adjacent the panel structure disposed immediately upstream in the fluid flow and the portion of the other duct adjacent said one panel structure has a larger cross-sectional area than the portion of that duct adjacent said upstream panel structure, the cross-sectional areas of said duct portions being such that the pressure drop in each portion of the duct adjacent each panel is approximately equal.

2. The electrical apparatus as specified in claim 1 wherein said panel structures include apertures which communicate with the assemblies mounted thereon and which enable the cooling fluid from the inlet duct to pass through said assemblies and into the outlet duct.

3. The electrical apparatus as specified in claim 2 wherein said panel structures each comprise a single panel.

4. The electrical apparatus as specified in claim 2 wherein said panel structures each comprise a plurality of closely spaced panels which are oriented parallel to one another and whose apertures are aligned.

5. In a high-voltage electrical apparatus composed of a plurality of semiconductor rectifiers held in heat-dissipating assemblies mounted on supporting panel structures in a housing, said housing having sidewalls enclosing said panel structures and having entrance and exit apertures for the ingress and egress of cooling fluid to the housing, the improvement comprising means mounting selected panel structures in an arrangement which forms walls of at least three ducts in said housing through which the cooling fluid is made to flow, said ducts being disposed on opposite sides of said panel structures with portions thereof adjacent hereto, a first one of said ducts communicating with said entrance aperture for carrying the cooling fluid to the mounted assemblies, a second duct communicating with an exit aperture for carrying said fluid away from some of said assemblies and a third duct communicating with an exit aperture for carrying said fluid away from the other of said assemblies, said panel structures being disposed in two groups, the panel structures in each group being generally parallel to and laterally offset from each other, said groups being disposed opposite each other to form said first duct therebetween, said first duct being of maximum cross sectional area at said inlet aperture and becoming progressively smaller in cross sectional area adjacent each panel structure in the downstream direction so that the pressure drop in each portion of the duct adjacent each panel structure is approximately equal.

6. The apparatus as described in claim 5 wherein said panel structures each comprise a single panel.

7. The apparatus as described in claim 5 wherein said panel structures each comprise a plurality of closely spaced panels which are oriented parallel to one another.

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