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TRANSFORMER PROTECTION

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My invention relates primarily to improvements in completely self-protected transformers having for their object the protection and continuity of the service rendered to the customers. More specifically, my object is to assure the user of the transformer a maximum degree of reliability at the minimum maintenance-expense.

In my Patent No. 2,066,935, of January 5, 1937, I showed the first completely self-protected transformer in which a serially connected circuit-interrupter was utilized for protecting the transformer, and in which a thermally responsive device was utilized for initiating an opening operation of the circuit interrupter, said thermally responsive device being in heat-exchanging relation to the transformer-oil, and being also electrically heated by the secondary current of the transformer, so that the thermally responsive device (usually a bimetal strip) would be cooled, by the oil, at the same rate as the copper of the windings, so that the temperature of the bimetal member would match the copper temperature at all times, regardless of the magnitude or the duration of the load, and throughout the entire range of permissible loads.

This first completely self-protected transformer, when designed as originally outlined, suffered a handicap by reason of the fact that the bimetal strip would theoretically trip out the circuit-breaker whenever the bimetal member reached its predetermined temperature for which it was set, which meant that the transformer would be taken out of service whenever the copper, and hence the insulation surrounding the copper, reached this same predetermined temperature, regardless of the length of time during which the insulation had been subjected to that temperature. It is well known to operating engineers, however, that it is feasible to subject a transformer to considerable overloads for short periods of time, without unduly shortening the life of the insulation, as the matter of insulation-failure is not a matter of the insulation failing instantly whenever it reaches a certain temperature, but merely a shortening of the life of the insulation when it is operated at higher and higher temperatures. Thus the A. I. E. E. Standards recognize the feasibility of a temperature of 250° for 5 seconds, 160° for one minute, and 105° continually.

This first completely self-protected transformer, as originally outlined, suffered an even worse handicap, in the practical aspects of maintaining approximately identical copper and bimetal temperatures, by reason of the fact that, if the

bimetal-member were designed to reach the same steady-state temperature as the copper on all loads which could be permitted to remain continuously on the transformer, it would perform poorly on heavier overloads which could not be left continuously on the transformer without overheating the transformer. During these short-time overload-conditions, a bimetal-member which would reach the same temperature as the copper on smaller, continuously permissible loads, would reach its critical limiting or tripping temperature before the copper reached even its permissible continuous-load temperature. Thus, far from permitting the copper to reach abnormally high temperatures for limited times under these so-called "usable overload" conditions, a bimetal-member, which was designed for a parity of temperature, as compared with the copper-temperature, would not permit the transformer to carry these "usable" limited-time overloads long enough for the copper to reach even the temperature which could be permitted continuously, whereas abnormally high copper-temperatures could easily be endured for these limited times, provided that a thermal protective-means could be devised for permitting the same.

It soon became apparent, therefore, that the job of designing a completely self-protected transformer had not been completely performed, in all of the desirable details which should be incorporated therein, and in such a manner as to meet the utmost of commercial requirements or desirabilities, provided that means could be devised for permitting the transformer to have this short-time overload capacity without automatically pulling it out of service by a circuit-breaker opening-operation.

With the foregoing problem in mind, the next step in the commercial development and perfection of completely self-protected transformers was that which was set forth in an application Serial No. 322,940, filed March 8, 1940, by Putman, Lockie, Leonard and myself, Patent No. 2,298,229, granted October 6, 1942, in which short-time overload-capacity was given to the transformer by altering the transient and steady-state relations between the rate of heat-transfer between the bimetal member and the oil, in comparison to the rate of heat-input into the bimetal member as a result of the passage of the transformer-current therethrough. In the transformer covered by this Putman et al. application, the proportionality between heat-input and heat-output of the bimetal member was changed from

the value recommended in my aforesaid patent, so that the bimetal-member would now run cooler than the copper, under continuously permissible load-conditions, and the setting of the trip-out temperature of the bimetal-member was correspondingly reduced, so that the transformer would be taken out of service at substantially the same copper-temperature as before, in response to long-continued heavy load conditions tending to abnormally overheat the transformer. Theoretical analysis, amply substantiated by tests and service-experience, demonstrated that this unmatching of the thermal characteristics of the oil-immersed bimetal member, as compared with the thermal characteristics of the oil-immersed copper, admirably served the purpose of giving the transformer not only a useful overload capacity for moderate time-periods of the order of $\frac{1}{2}$ to 2 hours, (as when the transformer might be required to take on an extra load while another circuit was being repaired), but it would also enable the transformer to successfully carry extremely short-time overloads of the order of a minute, without tripping out the transformer-breaker (as when the transformer might be required to take care of the starting-period of a large motor connected thereto).

This boon of short-time normal-temperature overload-capacity, and even short-time higher-temperature operating-ability, was given to the completely self-protected transformer at a price, however, and that price was a sacrifice of the ambient-temperature compensation which was enjoyed by the original completely self-protected transformer in which the bimetal-member and the copper were kept at the same temperature. By ambient-temperature compensation is meant the ability of the thermal protective device to limit the maximum copper-temperature to the same amount, summer or winter, that is, regardless of the ambient temperature outside of the transformer. It was found that the operation of the thermal member at a lower temperature than the copper permitted the copper to reach a higher temperature in winter, when the temperature-gradient between the copper and the oil is high, than in summer, when the oil was warmer, so that a transformer which was properly set to trip out at, or soon after, the attainment of a 105° temperature in summer would be permitted to become overloaded in winter, and if properly adjusted for cold-weather operation, the automatic thermal response would trip the transformer out of service before it had really been loaded up to its maximum safe capacity in summer.

In this state of the art, it was a primary object of my present invention to devise a different or additional means which would permit the transformer to be loaded up to substantially the same copper-temperature conditions, summer or winter, during steady-state loads, or long-continued loads or load-cycles, while still giving the transformer short-time overload-capacity, by permitting the copper to attain abnormally high temperatures for short periods of time, before tripping the transformer out of service.

It is an object of my invention, therefore, to provide means for giving the bimetal member a non-linear thermal response to the load-current of the transformer, so that the ambient-temperature compensation is obtained for all loads up to and including a certain "useful overload" range up to 2, 3 or 4 times full-load, as the case may be, (even higher in some small transformers),—and thereafter reducing the relative rate of current-

input into the bimetal member as compared to the load-current of the transformer, or otherwise changing the conditions of thermal response, so as to give the transformer the previously discussed short-time capacity with respect to extra-heavy loads for short periods of time, either in the range of a minute, or in the range of an hour, as in the Putman et al. transformer.

While the object of my non-linear current-response has hereinabove been set forth primarily from the standpoint of obtaining ambient-temperature compensation simultaneously with short-time overload-capacity, my invention also has, for an object, two other advantages not so often thought of as being associated with ambient-temperature compensation.

The first of these additional advantages, which constitutes an object of my invention, has to do with the proper coordination of two or more different kinds of protective devices for the transformer, in a manner which will perhaps be clearer on reference to the tripping-time curves shown in Fig. 13 of the Snyder Patent No. 2,198,489 of April 23, 1940, from which it will be seen that the different relay-responses must be coordinated over a time-range which is so long that it is necessary to split minutes, and sometimes even seconds, at the short end of the range, and it is necessary to coordinate hours of operation at the long end of the range, so that a logarithmic curve is necessary. Thus, on a power-transformer where such coordination is needed, there may be an instantly operating overcurrent-relay which may, or may not, be utilized, to trip out the circuit breaker in less than $\frac{1}{10}$ of a second when a certain fixed overload-current is reached; there is usually an inverse-time overcurrent-relay which will operate in anywhere from a second to a minute, in a predetermined overcurrent-range extending from several times the normal or full-load current to the short-circuit current-value; there is usually a protective link or fuse which also has an inverse-time characteristic extending anywhere from several seconds to several minutes, but set to operate so that it will not disconnect the transformer from service except for still higher overcurrent values; and finally there is the thermally responsive relay, responsive more or less to the copper temperature, which is sometimes required to have a time-characteristic which, at all points, lies in an intermediate position between the time-characteristic curve of the protective link and the time-characteristic curve of the inverse-time overcurrent-relay, or this coordination may be desired only in certain current-ranges. My non-linear current-response, in the means for electrically heating the bimetal member, constitutes an extremely useful instrument in coordinating the various relay times, aside from any advantages of ambient-temperature compensation.

A second additional object or advantage of my non-linear current-response is to delay the quickness of response of my thermal protective means at the short-time end of its tripping-time characteristic, so as to permit the transformer to hang on to extremely heavy overcurrents, even of short-circuit value, for a longer time than would otherwise be permitted by the thermal protective means. This delayed overcurrent action is extremely useful on distribution-transformers or on network-transformers in which it is desired that the transformers supply electrical power for burning off faults, rather than removing the transformer instantly from service as soon as a fault occurs.

With the foregoing and other objects in view, my invention consists in the apparatus, elements, combinations, methods and systems hereinafter described and claimed, and illustrated in the accompanying drawing, wherein:

Figure 1 is a diagrammatic cross-sectional view through a transformer, illustrating an application of my invention;

Figs. 2 and 3 are time-curves which will be referred to in the explanation;

Fig. 4 is a diagrammatic view of circuits and apparatus illustrating my invention in a power-transformer application in which a coordination is desired between the operating-times of the thermal protective device and other protective devices which are associated with the transformer; and

Fig. 5 is a diagrammatic view of circuits and apparatus illustrating the application of a number of my improved transformers in the form of network-transformers in which the time-coordination between the thermally responsive tripping of the circuit breaker and the melting of the line-fuses must be arranged to permit the transformer, if possible, to melt off any fault that occurs on the secondary network.

In Fig. 1, my invention is illustrated as being embodied in a transformer comprising a main metal tank or casing 1, which may be grounded at 2, containing oil 3, or other liquid cooling and insulating means, in which is immersed in magnetizable transformer-core 4, carrying the transformer-coils comprising the low-voltage winding 6 and the high-voltage winding 7. The coils 6 and 7 are made of insulating wires of copper or other electrical conductor, these wires being suitably insulated from each other, and from the core 4, and from the tank 1. In general, a certain amount of internal cooling is provided in the form of oil-ducts 8 which are disposed within the interior or mass of the coils 6 and 7, in order to decrease the temperature-gradient between the copper and the oil.

I also provide a thermally responsive device which is in heat-exchanging relation to the top of the oil, or the portion of the oil which is heated after cooling the transformer-windings. The thermally responsive member may take any one of different forms, and it is shown, for illustrative purposes, in its preferred form, comprising a bimetal-member 10 which is immersed in the oil 3, and which is provided with one or more projections or catches 11 which cooperate with a signalling-latch 12 and a tripping-latch 13 which are so adjusted that, as the bimetal-member 10 is heated, and bends to move its catch 11 away from latching-engagement with the latches 12 and 13, the signalling-latch 12 will be released at a temperature which is some 30° C. (or other desired amount) sooner than the tripping-latch 13. The thermally-responsive device 10—11—12—13 is illustrated as being of the type which is shown in a Leonard Patent No. 2,169,586 of August 15, 1939, or it may embody certain improvements such as are shown in a copending Leonard application Serial No. 421,787, filed December 5, 1941, or some other type of thermally responsive device may be utilized.

In the very schematically illustrated thermal-device which is shown in Fig. 1, the two latches 12 and 13 are normally set to be held, by the bimetal catch or projection 11, against the bias of their respective biasing-springs 14 and 15; and these latches have back-contacts 16 and 17,

respectively, which are closed when the respective latches 12 and 13 are tripped.

In the form of my invention which is shown in Fig. 1, a high-voltage or primary circuit is shown as comprising an incoming lead 20 which enters the casing 1 through a bushing 21, and which is protected against excess-voltage surges by means of a suitable self-clearing or valve-type lightning arrester or excess-voltage protective device 22, which is illustrated as being connected to the high-voltage lead 20 at a point 23 inside of the tank 1, the other terminal of the arrester 22 being grounded as by means of an electrical connection to the tank. The primary lead 20 now passes on, through a primary link or fuse 24, to the primary or high-voltage winding 7 of the transformer, and thence to a second or grounded primary lead 25 which is brought outside of the tank 1 through a bushing 26, and which is illustrated as being grounded at 27, although it will be understood that any other return-circuit connection may be made for completing the primary circuit through the high-voltage winding 7.

In the form of embodiment of my invention which is illustrated in Fig. 1, one terminal of the secondary or low-voltage winding 6 is connected to a secondary lead 30, which leaves the tank 1 through a bushing 33. The other terminal of the secondary winding 6 is illustrated as comprising a secondary lead 34, which leaves the tank 1 through a bushing 35. Before the secondary conductors 30 and 34 leave the tank 1, or before they leave an auxiliary compartment 36 which may be attached to the main tank-portion 1, they are respectively provided with lightning-arrester protection, as illustrated diagrammatically at 37 and 38.

In the form of my invention which is illustrated in Fig. 1, the signal-circuit contacts 16 of the thermally tripped latch 12 are utilized to energize an externally visible lamp 40, which may derive its power from any suitable source such as a potential transformer 41 located in the auxiliary box or compartment 36. The tripping contacts 17 are illustrated as being utilized to control the energization of the trip-coil 45 of a secondary circuit-breaker 46 which is serially connected in the secondary leads 30 and 34. The trip-coil 45 is shown as deriving its energy from the same potential-transformer 41 as the signal-light 40.

The bimetal-member 10 is electrically heated in response to a load-current of the protected transformer, and in accordance with my present invention the proportionality of this load-current response is non-linear, or the conditions governing the thermal response of the bimetal-member are otherwise changed, so that the proportionality between the heating-current of the bimetal-member 10 and the load-current of the transformer is, in its thermal effect, different for different values of the load-current. The means which I at present prefer for achieving this non-linearity of the thermal current-response is a saturating current-transformer 44, which is serially energized from the secondary lead 30, and which is carefully designed and calibrated so that it saturates at some definite predetermined useable overload current-value, such as $2\frac{1}{2}$ to 3 times the normal load-current of the transformer, so that, up to this saturating point, the current-response is substantially linear, or the transformation-ratio is substantially constant, whereas, after saturation begins, the current which is de-

livered to the bimetal-member 10 bears a smaller ratio to the current flowing in the secondary lead 30 of the transformer.

In analyzing the operation of my invention, it is convenient to refer to the "normal" conditions as the full-load current of the transformer, which I shall designate I_n . Under the normal load-conditions of the transformer, the final, or steady-state, value of the copper-temperature T_c is higher than the oil-temperature T_o by the so-called "normal" gradient, which is designated K , and which is expressed in °C. At any other load, other than the normal load I_n , such as the load LI_n , the copper temperature-gradient G_c , or the temperature-difference between the copper and the oil, is equal to $G_c = KL^2$, where x is a radiation-constant of the transformer, usually approximating the value $x=2$, so that the copper temperature-gradient G_c becomes $G_c = KL^2$, approximately.

The bimetal temperature-gradient G_b depends upon the square of the bimetal current, which, in the non-saturated condition of the current-transformer, may be regarded as LI_n , the bimetal resistance R , and the rate of heat-transfer between the bimetal and the oil, which may be designated aq , where a is the effective heat-dissipating area of the bimetal-member, and q is the watts radiated in heat from the bimetal member to the oil for each unit of heat-dissipating area of the bimetal member, and also for each degree of the temperature-gradient G_b between the bimetal member and the oil. The approximate formula for the gradient of the bimetal to the oil is

$$G_b = \frac{I_n^2 L^2 R}{aq}$$

In the non-saturated condition of the current-transformer 44, the thermal characteristics of the bimetal member are preferably so chosen that the temperature-gradient between the bimetal and the oil is at all times equal or approximately equal to the temperature-gradient between the copper and the oil, or

$$K = \frac{I_n^2 R}{aq}$$

The effect of this relationship is to give the transformer ambient-temperature compensation, as hereinabove explained, but no ability to operate, for short periods of time, at an increased copper-temperature, or, practically speaking, even at the permissible steady-state copper-temperature, as previously noted.

Furthermore, if the overload is very excessive, the final copper-temperature which is permitted by such the relationship just mentioned is less than the predetermined intended amount, if the overload-condition follows the normal full-load operating-condition of the transformer, as is shown qualitatively in Fig. 2, wherein the curves 50 and 51 show the amounts of overload-currents which are necessary to bring about a thermally responsive tripping of the circuit-breaker 46 in different tripping-times, expressed in hours, the full-line curve 50 representing the condition in which the overload in question follows a period of no-load operation of the transformer, and the dotted curve 51 representing a condition following full-load operation of the transformer. In Fig. 2, I have also indicated the final copper-temperatures which are permitted by the bimetal member for the different tripping-times, the full-load curve 52 showing the copper-temperatures

which are attained when the overload-period follows a no-load operating-condition, and the dotted-line curve 53 showing the final copper-temperature which is permitted when the overload-period follows full-load operation of the transformer. These same conditions are approximately attained summer or winter, that is, regardless of the ambient temperature, as indicated in Fig. 2.

In Fig. 3, I have shown the conditions which are obtained when the temperature-gradient between the copper and the oil is made larger than the temperature-difference between the bimetal and the oil, that is, when

$$K > \frac{I_n^2 R}{aq}$$

It will be noted that the final copper-temperature which is permitted for extreme overloads which endure for only an hour or two before a tripping-operation is obtained has been considerably increased, as indicated by the humps in the curves in Fig. 3. In this figure, the upper full-line curve 54 indicates the final copper-temperatures which are obtained in winter, when the overload-period follows a period of no-load operation of the transformer, while the dotted-line curve 55 shows the same condition following full-load. The lower full-line curve 56 represents the copper-temperatures which are permitted in summer-time, following a no-load period of operation of the transformer, while the dotted curve 57 shows the same thing following full-load operation. It will be noted, from Fig. 3, that short-time overload capacity has definitely been given to the transformer by making the copper-gradient K greater than the bimetal-gradient $I_n^2 R/aq$, but this has been done at the expense of ambient-temperature compensation.

The particular advantage of my present invention will thus readily be apparent, in which I retain the full advantages of ambient-temperature compensation, as shown in Fig. 2, by utilizing a strictly linear current-response for all currents up to and including the largest load which can be permitted continuously, corresponding to $L=2.5$ or 3, or, in general, the range from $L=2$ to $L=4$, or sometimes more, depending upon the particular transformer and the particular type of service for which it is intended. This is the important range from the standpoint of long-time tripping-times, that is, from the standpoint of heavy loads which endure for many hours or days, so that the transformer is always, or frequently, running nearly as hot as it is safe to let it run at all. Under these circumstances, it is very essential that the transformer shall attain the same permissible copper-temperature summer or winter, that is, regardless of the temperature of the outside air, and regardless of the temperature of the oil. It will be noted that my present invention retains this desirable ambient-temperature compensation over the load-range where it is primarily needed.

In accordance with my invention, as previously noted, saturation begins to set in, in the current-transformer 44, at a certain definite overload-value, which is below the permissible short-time overload limit of the transformer, so that, beyond this point, the response-characteristic begins to change over, from the conditions depicted in Fig. 2 to the conditions depicted in Fig. 3. This change is effective only in the short-time ranges of the tripping-times, because, where the overload-current is not excessive, there will be no

saturation, and the tripping-time will be longer, thus giving approximately a straight line or constant-temperature characteristic as indicated at 52 in Fig. 2, which holds constant summer or winter. It is true that the exact amount of short-time overload which my invention permits, because of the saturation of the current-transformer 44, is somewhat different in summer and in winter, and it is possible to add means for compensating for this difference, but to date I have not deemed it necessary to go to this additional expense, as the essential thing seems to be to provide a reasonable, but not critical, amount of over-temperature operation of the copper for heavy-overload conditions which endure for but a short time, and this object is admirably achieved in my present invention, as described.

In Fig. 4, I have illustrated the application of my invention to a three-phase power-transformer wherein the same reference-characters as utilized in Fig. 1 have been repeated, so far as applicable, the different phases being distinguished by the letters A, B and C. Instead of utilizing a single saturating current-transformer 44 in each phase, I have illustrated, in Fig. 4, the use of a standard or non-saturating current-transformer 60, in each phase, which is utilized to energize an inverse-time overcurrent-relay 61, as well as a saturable auxiliary current-transformer 62, the latter being utilized to energize the respective bimetal-members 10A, 10B and 10C. The inverse-time overcurrent-relay 61 has make-contacts 63 which are connected in parallel with the respective tripping-contacts 17A, 17B and 17C for energizing the respective trip-coils 45A, 45B and 45C. The auxiliary saturating current-transformers 62 have the same saturating-characteristics previously explained for the current-transformer 44 in Fig. 1. Since the design of the saturating current-transformer is fairly difficult, it is frequently convenient to design it for use in a standard secondary circuit, where the normal or full-load current is, say, 5 amperes, rather than designing a separate saturating transformer for each of the normal load-currents of a long line of thermally protected main-transformers of many different sizes.

Fig. 4 illustrates an application of my invention in which the problem of coordinating the tripping-times of the primary fuses 24, the thermal elements 10A, 10B and 10C, and the inverse-time overcurrent-relays 61 has frequently heretofore presented difficulties because of the tendency of the thermal response to operate more quickly, for short-time overloads, than is permitted by the inverse-time overcurrent relay 61, thus necessitating a slowing down of the tripping-time of the thermal element at the short-time end of its range of operation, that is, during conditions of excessive overcurrents which can be tolerated for but a short time, but which need to be tolerated for a considerably longer time than would be permitted by the thermal element, if a non-linearity in the current-response were not introduced, as by means of my current-transformer saturation.

In Fig. 5, I have illustrated my invention, by means of a single-line diagram, in an application in which nine of my improved completely self-protected transformers 70 are utilized to transform electrical energy between a high-voltage primary network 71, and a low-voltage secondary network 72. It will be understood that each one of the transformers 70 in Fig. 5 represents, or

may represent, a complete transformer such as is shown in either Fig. 1 or Fig. 4 of my drawing. In serving such a network, it is considered good operating practice to burn off secondary faults by burning away the faulted current-conductors, thus severing the conductors and clearing the fault, rather than by having the transformers become disconnected from the primary and thereby dropping all of their load. Since the time-constant of the bimetal element is short, and since its action is very rapid, under high-current overloads, it is desirable to delay the action under these circumstances, through the use of saturating current-transformers, as previously described. Ordinarily, in such service, loads in excess of 500% load, or $L=5$, are considered short-circuits. Useful overloads seldom exceed 250%. Under these conditions, the straight-line characteristic of the current-transformer should maintain up to 250 to 500% overload, and then the current-transformer should saturate to delay the operation of the thermal relay at any currents higher than the saturating value.

In network service such as is shown in Fig. 5, a sometimes difficult problem of coordination has existed in adjusting the time-characteristics of the secondary fuses or breakers 73, which are interposed at various points in the secondary network, the primary fuses 24, and the thermally controlled secondary breakers 46 of the various protected transformers, as the secondary line-fuses or breakers 73 must be arranged to isolate a line on which there may be a fault before the secondary breaker 46 can open in response to the thermal protection of the transformer, and as this secondary transformer-breaker 46 must, in turn, open before the primary link 24 opens, my non-linearly current-responsive thermal protective device finds a very useful application in such a system, because of the opportunity which it provides for correlating the short-time range of the thermal protection without disturbing the ambient-temperature compensation which is obtained in the long-time operating-ranges.

I claim as my invention:

1. In combination, an oil-cooled transformer, a thermally responsive device in heat-exchanging relation to the oil, means for electrically heating said thermally responsive device in response to a load-current of the transformer, current-responsive means for causing the temperature-gradient between the thermally responsive device and the oil to be disproportionately smaller at certain currents in excess of a predetermined overcurrent than at the full-load current, said predetermined overcurrent being smaller than the permissible short-time overload of the transformer, and means responsive to a predetermined temperature of the thermally responsive device while the transformer is in useful operation.

2. In combination, an oil-cooled transformer, a thermally responsive device in heat-exchanging relation to the oil, electrical heating-means for heating said thermally responsive device in response to a load-current of the transformer, the proportionality of the thermal response being weaker at certain useable overload currents in excess of a predetermined overcurrent than at the full-load current, and means responsive to a predetermined temperature of the thermally responsive device while said transformer is in useful operation.

3. In combination, an oil-cooled transformer, a thermally responsive device in heat-exchanging relation to the oil, electrical heating-means

including a non-linear current-responsive device for heating said thermally responsive device in accordance with a non-linear response to a load-current of the transformer over a range including the permissible short-time overload of the transformer, and means responsive to a predetermined temperature of the thermally responsive device while said transformer is in useful operation.

4. In combination, an oil-cooled transformer, a thermally responsive device in heat-exchanging relation to the oil, electrical heating-means for heating said thermally responsive device in response to a load-current of the transformer, said electrical heating-means including, as a source of heating-energy, a saturable current-transformer which begins to saturate at a predetermined value of overcurrent, said predetermined overcurrent being smaller than the permissible short-time overload of the transformer, and means responsive to a predetermined temperature of the thermally responsive device while the transformer is in useful operation.

5. An electrical transformer having an insulated conductor constituting a winding, a magnetizable core, a cooling and insulating oil, and a tank therefor, in combination with: a thermally responsive device in heat-exchanging relation to the oil; electrical heating-means for heating said thermally responsive device in response to a load-current traversing said conductor; the rate of heat-exchange between the thermally responsive device and the oil, and the rate of current-responsive heating-input into the thermally responsive device, being so balanced, during certain load-currents including the full-load current, that the temperature of the thermally responsive device approximates that of the conductor, the proportionality of the response being weaker at certain usable overload currents in excess of a predetermined overcurrent; and means responsive to a predetermined temperature of the thermally responsive device while the transformer is in useful operation.

6. In combination, an electrical energy-translating device, a cooling medium therefor, a thermally responsive device in heat-exchanging relation to a portion of the cooling medium which has become heated by said energy-translating device, means for electrically heating said thermally responsive device in response to a load-current of said energy-translating device, current-responsive means for causing the temperature-gradient between the thermally responsive device and the cooling medium to become disproportionately weaker at certain usable overload currents in excess of a predetermined overcurrent than at the full-load current, and means responsive to a predetermined temperature of the thermally responsive device while said electrical energy-translating device is in useful operation.

7. In combination, an electrical energy-translating device, a cooling medium therefor, a thermally responsive device in heat-exchanging relation to a portion of the cooling medium which has become heated by said energy-translating

device, electrical heating-means for heating said thermally responsive device in response to a load-current of said energy-translating device, the proportionality of the thermal response being weaker at certain currents in excess of a predetermined overcurrent than at the full-load current, said predetermined overcurrent being smaller than the permissible short-time overload of the energy-translating device, and means responsive to a predetermined temperature of the thermally responsive device while said electrical energy-translating device is in useful operation.

8. In combination, an electrical energy-translating device, a cooling medium therefor, a thermally responsive device in heat-exchanging relation to the cooling medium of said energy-translating device, electrical heating-means including a non-linear current-responsive device for heating said thermally responsive device in accordance with a non-linear response to a load-current of the energy-translating device over a range including the permissible short-time overload of said energy-translating device, and means responsive to a predetermined temperature of the thermally responsive device while said electrical energy-translating device is in useful operation.

9. In combination, an alternating-current energy-translating device, a cooling medium therefor, a thermally responsive device in heat-exchanging relation to the cooling medium of said energy-translating device, electrical heating-means for heating said thermally responsive device in response to a load-current of said energy-translating device, said electrical heating-means including, as a source of heating-energy, a saturable current-transformer which begins to saturate at a predetermined value of overcurrent, said predetermined overcurrent being smaller than the permissible short-time overload of the energy-translating device, and means responsive to a predetermined temperature of said thermally responsive device while said electrical energy-translating device is in useful operation.

10. In combination; an electrical energy-translating device having an insulated conductor; a cooling medium therefor; a thermally responsive device in heat-exchanging relation to a portion of the cooling medium which has become heated by said energy-translating device; electrical heating-means for heating said thermally responsive device in response to a load-current traversing said conductor; the rate of heat-exchange between the thermally responsive device and the cooling medium, and the rate of current-responsive heating-input into the thermally responsive device, being so balanced, during certain load-currents including the full load-current, that the temperature of the thermally responsive device approximates that of the conductor, the proportionality of the response being weaker at certain usable overload currents in excess of a predetermined overcurrent; and means responsive to a predetermined temperature of said thermally responsive device while said electrical energy-translating device is in useful operation.

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