

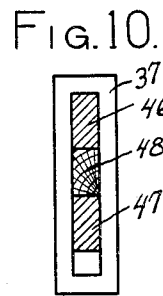
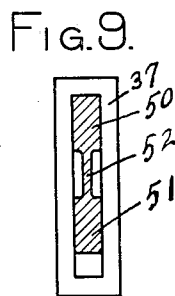
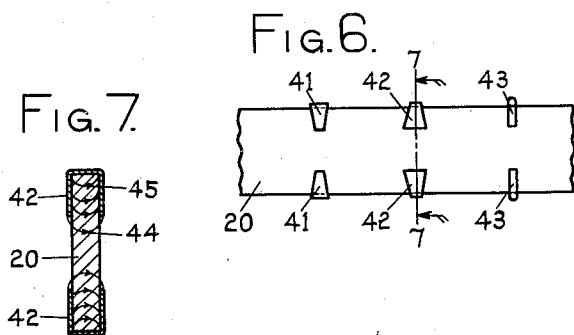
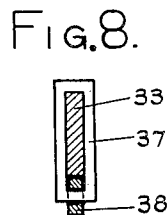
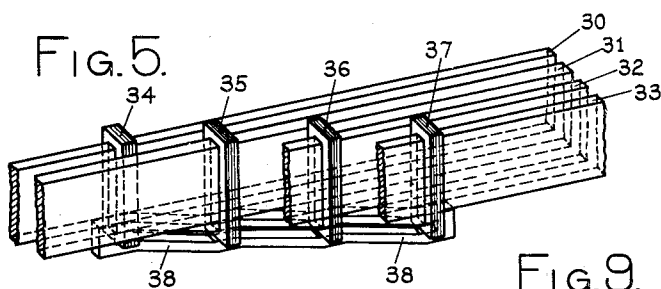
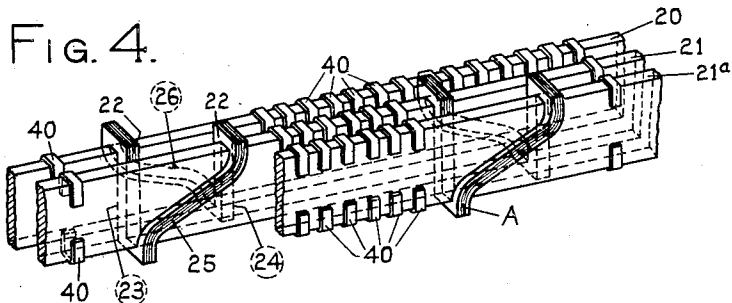
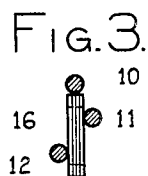
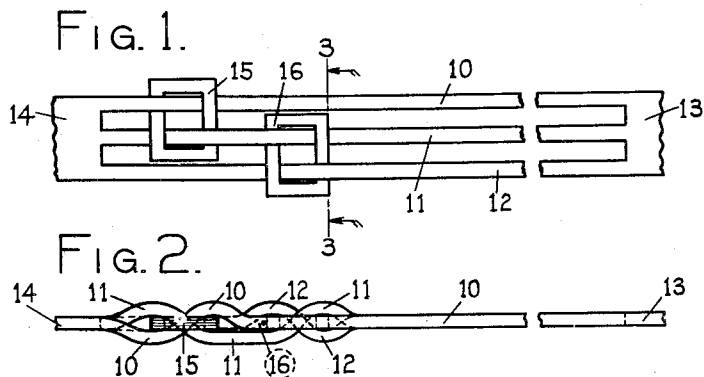
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INDUCTIVE ALTERNATING CURRENT REGULATOR FOR BUS BARS

Filed May 19, 1921



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UNITED STATES PATENT OFFICE

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INDUCTIVE ALTERNATING-CURRENT REGULATOR FOR BUS BARS

Application filed May 19, 1921. Serial No. 470,845.

My present invention relates to means for regulating and balancing the distribution of alternating current in electrically parallel conductors, that is, conductors connected to jointly carry the current to be transmitted. The most common instance for the application of this invention is in bus-bar construction where large currents are to be transmitted, but the invention is applicable where small currents are to be transmitted but where the frequency is comparatively high.

One of the objects of my invention is to transmit alternating current in parallel conductors in substantially equal quantities, that is, divide the current substantially equally among them or divide it in definite proportions.

Another object is to accomplish the above object by increasing the reactance or inductance only slightly in the system and thereby not impair the regulation of the system.

Another object is to accomplish this regulation without modifying the bus-bar construction, so that the conductors may be ventilated by spacing them apart as is now common practice.

Another object is to positively and automatically regulate the division of current among the several conductor elements regardless of the influence, either constant or variable, that other current carrying conductors in the vicinity may have on some of the bus-elements, and not merely divide the current by adjusting the respective constants of the conductor-elements such as their resistance, inductance and capacity.

Another object is to provide adjustable means to improve the distribution of current flow in the conductors themselves.

Other objects will be apparent from the following subjoined description in connection with the claims and drawings which form a part of this specification. The drawings forming a part of the application show several specific applications of my invention in which like reference characters indicate like parts in the several views of the drawings and in which:—

Fig. 1 shows one form of my invention where the current is regulated between three

electrically parallel conductors by applying two of the regulators thereto.

Fig. 2 is a plan view of the device shown in Fig. 1.

Fig. 3 is a sectional view taken on the line 3—3 Fig. 1.

Fig. 4 is an isometric view of a modified form of the invention showing only a portion of the conductors, which also shows the novel means of improving the distribution of current flow in the conductors themselves.

Fig. 5 is a similar view of another modification.

Fig. 6 shows a strap conductor having several modified forms of reactance members attached thereto.

Fig. 7 is a sectional view taken on the line 7—7 Fig. 6.

Fig. 8 is a sectional view taken through the loop conductor and bus-element adjacent to one of the cores in Fig. 5.

Figs. 9 and 10 show modified forms of bus-elements with a core thereon, and with the loop conductor omitted.

Fig. 1 shows one conductor of an alternating current bus-bar, the conductor being divided into three strips, rods, cables or bus-elements 10, 11 and 12 to reduce eddy currents. It is well known that eddy current losses are much larger in circular or square conductors than in conductors of rectangular cross-section, and that they are very large for conductors of large size, and are much reduced by subdividing the conductors, such subdivision also allowing a better radiation of the heat generated therein.

In the transmission of large quantities of power by alternating current it is noted that the current is not divided between the several conductors equally although the several conductors are of the same length and cross-sectional area. This unequal distribution is due to skin effect, as it is commonly called, which is a lower current density at and near the center of a conductor, conductor-element or group of conductors jointly carrying a certain current, if uninfluenced by currents in other conductors in close proximity thereto. This lower current density is due to the additional inductive reactance set up there by

the magnetism which links the inner portion of the conductor and not that portion of the conductor lying near the outer edge of the conductor or conductor elements. These bus-elements are connected at the points 13 and 14 as is common in bus-bar construction or they may not be connected together except at the machine or transformer terminals at both the generating and distributing end of the bus-bars. In such construction it is noted that the conductor 11 carries much less current than the conductors 10 and 12 even though they have the same electrical resistance. This unequal distribution is caused by the skin effect already referred to. To equalize the current flow through conductors 10 and 11 an iron core 15 is placed in position so that the conductors pass through the core 15 from opposite sides as clearly shown in Figs. 1 and 2. The core 15 is made of laminae of sheet iron or of round or square wire and may be assembled after the bus is already installed. This core should be insulated from the bus-elements, though very little insulation is necessary, a sheet of paper being sufficient. The positioning of the conductors in the core is such that the additional magnetic lines surrounding conductor 11 only and not conductors 10 and 12 may be neutralized by the additional current in the conductors 10 and 12 over the amount flowing in conductor 11 and in this way, so to speak, reduce the inductive reactance of conductor 11. If the unequal distribution of the current between conductors 10, 11, and 12 were due to unequal resistances of the conductors the balancing core on the conductors would not balance the current very satisfactorily, although it would do so. This is accounted for by the fact that the voltage induced in conductor 10 by the core 15 lags 90° behind the magnetic flux, which magnetic flux is in phase with the current in conductor 10; therefore placing the voltage 90° out of phase with the current and also 90° out of phase with the IR drop or counter E. M. F. due to resistance. The voltage induced in conductor 10 due to the core 15 is, however, in phase with the E. M. F. due to self-inductance and, therefore, aids in reducing the current in conductor 10, and since the conductor 11 passes through the core from the reverse side, the voltage induced in conductor 11 by the core is such that it will increase the current therein. Therefore, the current will be automatically and positively regulated so as to divide the currents practically equally between them. The same is true by the action of core 16. Therefore, if the current is balanced between conductors 10 and 11 and between 11 and 12 it must also be balanced between 10 and 12. It is apparent from the above that the current in conductor 11 will be equal to the current in conductor 10 minus the magnetizing current of core 15, which is very small

and approximately 90° out of phase therewith.

It is therefore apparent that the current may be divided between any two bus-elements regardless of outside magnetic influence due to other bus-bars and the like

The modifications shown in Figs. 4 and 5 are especially well adapted to regulate current distribution in modern bus construction in which copper straps are set vertically and spaced from each other about the distance of their thickness. This materially reduces eddy currents and gives good ventilation, but it is found that due to the skin effect, the middle bus-elements in case three or more of the copper straps are used, carry considerably less current. In Fig. 4 three such copper straps 20, 21 and 21^a are shown which constitute parallel elements of a bus-bar. The bars or straps 20 and 21 for the purpose of illustration will be presumed to carry unequal currents due to the action of skin effect or currents in other bus-elements or other bus-bars, not shown. An iron core 22 made of iron wire, or laminae, is shown wrapped or wound about the copper straps or bus-elements in the form of a figure 8, with crossing parts of the figure 8 spaced apart to minimize the leakage of magnetic flux at this point. The figure 8 core is composed of two Z bars, 23 and 24, which are placed between the copper straps 20 and 21 oppositely, and the ends of these Z bars, 23 and 24, are connected together by two S bars, 25 and 26. The operation of this core is substantially the same as those described in connection with Fig. 1. If it is desired to divide the currents in the ratio of two to one, two wraps or turns of the iron will be made around one of the bus-elements instead of one, and so on.

The figure 8 core A shown on bus-elements 21 and 21^a is identical to and functions like the core just described and no further description is thought necessary.

Fig. 5 shows another form of the invention applied to four presumably unbalanced bus-elements, 30, 31, 32 and 33. The bus-element 30 is surrounded by a closed core of iron 34, rectangular in form and the other bus-elements are surrounded by similar cores 35, 36 and 37. These cores are sufficiently long to allow a heavy loop conductor 38 having one or more turns to be placed thereon. In the drawing a single turn winding is shown and the single turn forms a closed loop interlinking the cores 34, 35, 36 and 37. It is apparent that the currents in all of the bus-elements will set up a voltage in the loop conductor 38, in the same direction, which voltage will set up a current therein, equal to the average of the currents in bus-elements 30, 31, 32 and 33, and flowing in the opposite direction to the currents in the bus-elements. Therefore the current in loop conductor 38 will be larger than the current in one or more of the bus-

elements 30, 31 or 33 and consequently set up a magnetic flux in the opposite direction to the magneto-motive-force set up by the current in that bus-element, which magnetic flux will produce a voltage in the opposite direction to that of the inductive reactance drop, and thereby increase the current in that bus-element to the extent of making this current substantially equal to the current in loop conductor 38, regardless of what outside influence may act toward unbalancing the currents.

The secondary windings, or loop conductors 38, on these cores may be used for the same purpose that secondary windings of current transformers are used for, that is, for actuating meters, relays or other current responsive devices. It is, therefore, apparent that the current may be equally distributed between any number of bus-elements by placing an iron core about each bus-element and passing a single loop conductor through all the cores. If the current is to be divided in different proportions than one to one, the number of turns on the several cores must be varied accordingly.

In addition to the means for regulating the distribution of current between several bus-elements, my invention comprises an adjustable means to improve the distribution of current in the bus-elements themselves. This means comprises a plurality of paramagnetic U shaped members 40 preferably made of sheet iron and frictionally held in place as shown in Fig. 4. These U shaped members may, however, be fastened to the bus-elements by shellac or glue and may be so spaced as to give a good current distribution in the bus-element. The U shaped members may be any design depending on the skin effect to be overcome, as shown by member 41, which is beveled toward the ends, member 42 which is beveled away from the ends, and member 43 which comprises a round wire bent in the form of a U. By spacing these U shaped members to suit the particular circumstances, along the top and bottom edges of the bus, the inductive reactance is increased to any desired amount and the current is crowded toward the middle of the bus-element.

Further the magnetic line, such as 44, Fig. 7, which bridges the U at its ends, cuts every portion of the conductor within said U while the magnetic line 45 merely cuts a small top portion of the conductor. It is, therefore, apparent that these U shaped members may be so placed along the bus-elements to greatly improve the current distribution therein. Although the current distribution between such U shaped members is not quite as good as it is directly under the same, it is substantially as good especially if these members are small and arranged close together.

The distribution of current in the bus-elements may be much improved by making it

smaller in cross-section near its middle and thereby increase the current density at this point. This may be done by making the cross-sectional area in the form of an I, comprising the top and bottom heavy portions 50 and 51 and the intermediate web-portion 52, Fig. 9. If desired the web-portion may be entirely omitted leaving the two conductors 46 and 47, Fig. 10. Further, if desired, a spacing member 48 of wood or suitable insulating material may be used as a spacer between the conductors 46 and 47. The middle portion of a rectangular conductor carries very little current due to the skin effect, and therefore by the construction shown in Figs. 9 and 10 a much better current distribution per unit cross-sectional area is obtained, and such construction may be used in connection with any one of the regulating means above described.

Having described several specific forms of my invention, I desire to have it understood that they were used for the purpose of description only and that they do not exhaust the method and means of applying my invention.

What I claim and desire to secure by Letters Patent is:—

1. In an alternating current system of distribution, a plurality of electrically parallel conductors connecting a source of current and a load a portion of said system having said conductors constructed rectilinear and arranged substantially parallel mechanically, and means in said portion automatically to regulate the distribution of current between said conductors by causing current in one conductor to induce a voltage in the same direction as said current in an adjacent conductor.

2. Means for automatically distributing the flow of alternating current between two conductors in multiple comprising, a laminated link of magnetic material readily disassembled of figure 8 configuration, said link being so shaped that the crossing parts thereof are displaced far enough to prevent excessive leakage of flux.

3. In an alternating current bus-bar construction, a plurality of mechanically parallel conductors in multiple electrically having a cross-sectional configuration advantageous in avoiding skin effect, a laminated link of magnetic material readily disassembled and of a configuration to link one of said conductors in one direction and another conductor in the other direction.

4. In an alternating current system of distribution, a plurality of electrically parallel conductors, a section thereof being substantially parallel mechanically and links each having a single magnetic circuit of figure 8 configuration associated with pairs of said conductors.

5. A transformer core consisting of a link of laminated magnetic material having a

single magnetic circuit of figure 8 configuration.

6. A transformer core comprising a link of laminated magnetic material having a single magnetic circuit of figure 8 configuration, said link being so constructed that the crossing portions of figure 8 are out of contact with each other.

7. A transformer for transforming alternating current comprising, two conducting members electrically connected in multiple, and a single magnetic circuit consisting of laminated iron independently surrounding each of said conducting members.

8. Means for transforming alternating current comprising, a plurality of conductors, and means having a single magnetic circuit for magnetically coupling said conductors by a link having individual turns surrounding each of said conductors.

9. A transformer comprising, parallelly arranged rectilinear primary and secondary conductors, and means for inducing an electro-motive-force in said secondary conductor by said primary conductor which is in an opposite direction in space to that of the counter-electro-motive force induced in the primary conductor.

10. Means for distributing the flow of alternating current between two conductors in multiple comprising, a magnetic link of figure 8 configuration, said link being so shaped that the crossing parts thereof are displaced far enough to prevent excessive leakage of flux.

In testimony whereof I affix my signature.
OSCAR H. DICKE.