LOAD IMPEDANCE RESPONSIVE FEEDBACK FOR VARIABLE REACTANCE TRANSFORMER

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SUMMARY OF THE INVENTION

It is an object of the present invention to overcome the disadvantages of the prior art and to provide a variable transformer which will control the power applied to a variable load in accordance with the impedance of that load and will transform voltage and current, both functions being performed in a single unitary structure.

A further object of the invention is to provide a variable reactance transformer for controlling the current to a resistance furnace load in accordance with the impedance of that load.

An additional object of the invention is to provide a variable reactance transformer having both a feedback control and an external control, whereby the system is sensitive to load impedance, and wherein control can be obtained through a smaller and less expensive external control unit than was possible with prior devices.

It is a further object of the invention to provide a variable reactance transformer control for a variable impedance load which will respond to fault conditions in the load to prevent circuit damage.

A further object of the invention is to provide a modifiable variable reactance transformer which has particular utility in the control of electric furnaces by providing a feedback arrangement which gives automatic control in response to changes in the load impedance. This invention permits an electric furnace to be turned on and gradually brought up to the desired temperature without the shock of high current bursts that are produced in presently used silicon controlled rectifier units. The transformer is comprised of a main annular core and two auxiliary, or control, annular cores which carry toroidal windings. The main core carries the secondary, or load, windings of the transformer as well as the feedback supply windings. The auxiliary cores each carry balanced but series opposed external control windings operated from an external control source such as a magnetic amplifier. The latter cores also carry balanced, series opposed feedback control windings supplied from the feedback supply windings. The primary input windings are provided for each turn of the primary encompassing all three cores in a toroidal winding. In a preferred construction, the secondary, feedback and control windings are adjacent their respective cores, with the primary being wound outside these windings.

Although the variable reactance transformer is suitable for use with any variable load, its unique operating features make it particularly valuable with a load such as an electric resistance furnace. When the load impedance presented by a furnace is at a low value, as when the furnace elements are cold, there tends to be a high current in the secondary winding of the transformer. The low load impedance means that most of the flux in the main core will go to producing load current; thus, only a small feedback current will be induced. This low feedback current, in turn, varies the saturation level of the control cores in a direction to increase their reactance and thus to increase the impedance of the variable reactance transformer. The increased impedance of the transformer reduces the output load current. As the electric furnace resistance elements heat up, their impedance increases, tending to decrease the load current. This permits a larger feedback current to be induced, increasing the saturation of the auxiliary cores and reducing their reactance. This reduced impedance of the transformer permits the load current to gradually increase until the system reaches full load power when the furnace resistance element is at the proper temperature. Thus, the transformer senses and responds to the load impedance.

This response to load impedance is particularly useful.
when a short circuit develops in the furnace elements. Such a condition produces high currents in both the furnace and the control circuitry which, in prior systems, could cause considerable damage before the circuit breakers could respond to cut off the current supply. In the present system, on the other hand, the start of such high fault currents immediately increases the impedance of the variable reactance transformer and reduces its output. The operation of the present system has been demonstrated by dropping a barter across the output terminals of the variable reactance transformer when it is operating at full power to produce a sudden and complete short circuit condition. The current output immediately dropped to a low level, the change in load current level occurring sufficiently quickly to preserve suchage to the system and to prevent the circuit breakers from opening. No other known system is capable of reacting in this manner. Although some transient peaks were present immediately upon occurrence of the short circuit, the response of the variable reactance transformer of the present invention was sufficiently fast to limit both their amplitude and duration enough to prevent damage to the system.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features which are a characteristic of the invention are set forth with particularity in the appended claims, but the invention and its objects will be understood more clearly and fully from the following detailed description taken in conjunction with the accompanying drawings in which the single figure is a schematic diagram of a variable reactance transformer constructed in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Turning now to the schematic diagram of the single figure, there is illustrated a variable reactance transformer circuit connected in accordance with the principles of the present invention. The transformer is comprised of a main core 12 and two auxiliary cores 14 and 16. These cores are annular in shape and are composed of any suitable magnetic material. They are so proportioned that the auxiliary cores 14 and 16 may become saturated when under the influence of a normal range of external control and feedback current control. Neither the auxiliary cores nor the main core 12, however, exhibit the so-called "square-loop" hysteresis curves, but preferably are of conventional magnetic materials.

Auxiliary cores 14 and 16 carry external control windings 18 and 20, respectively, connected in series opposition through a variable control resistor 22 to the output of an external control circuit and feedback control current. Neither the auxiliary cores nor the main core 12, however, exhibit the so-called "square-loop" hysteresis curves, but preferably are of conventional magnetic materials. The magnetic amplifier may be of conventional construction, providing an output current having a maximum value of 2 amperes. The output of the magnetic amplifier is controlled by means of a variable DC source 26 and is supplied with AC power from a suitable AC source 28.

A secondary winding 32 is wound on the main core 12 and supplies the controlled and transformed output current to a load device 35 connected between terminals 34 and 36. As has been noted, the load device may be the resistance elements are diagrammatically indicated in phantom at 37 and of an electric furnace, which elements may, for example, exhibit a resistance of 0.05 ohms at maximum temperature. The secondary winding 32 is coupled to the main core 12 only, for isolation from the DC control currents.

Surrounding all three of the cores 12, 14 and 16 is the unitary primary winding 40 which is connected at terminals 42 and 44 to a source of alternating current. As diagrammatically illustrated, the turns of windings 40 are not separately wound on each of the three cores, but each turn of the primary winding passes around all three cores. This primary winding normally carries the input current to the device, which current is to be transformed and/or controlled. Where a furnace resistance element is to be supplied, the power source to which the primary winding is connected may be a 480 volt AC line, with the primary winding carrying a full load current of approximately 63 amperes.

The transformer windings so far described are those which are the windings illustrated and discussed in my above-mentioned Patent No. 3,343,074. The improvement represented by the present invention is illustrated by feedback winding 50 which is located on main core 12 and thus is responsive to the changing flux induced within that core. The output of feedback supply winding 50 is applied across a potentiometer 52 having a slidable arm 54 which permits the feedback current to be varied. This variable output is applied across the primary winding of a feedback transformer 56, the primary being connected between slidable arm 54 and one end of potentiometer 52. The secondary winding of transformer 56 is fed through a full-wave rectifier comprised of rectifiers 58 and 60 having their cathodes connected to respective ends of the secondary winding and their anodes connected in common to a DC feedback line 62. The secondary winding of transformer 56 has a center tap to which is connected the second line 64 of the DC feedback circuit. Connected in series across lines 62 and 64 are the feedback control windings 66 and 68 which are wound on auxiliary cores 14 and 16, respectively. Feedback control windings 66 and 68 are connected in series opposition to each other, but are wound on their respective cores in such a direction as to be additive to the effect of the external control windings 18 and 20 also wound on the respective auxiliary cores. The circuit relationship of the various control windings is illustrated in the drawing in conventional manner by polarity dots, and since these windings are polarity sensitive, they must be connected as illustrated to obtain the desired control results. The two auxiliary cores are driven along their saturation curves in opposite directions by reason of the stated connection of the windings, and thus each core is adapted to control one half-cycle of the applied current, with the two auxiliary cores working together to provide balanced full wave control.

The physical relationship between the several cores and between the cores and their respective windings has not been illustrated herein, since such relationships are fully illustrated and described in my prior Patent No. 3,343,074. Thus, in a preferred embodiment, the main core 12 would be sandwiched between the auxiliary cores 14 and 16, the cores being as closely adjacent one another as the bulk of the windings will permit. The cores are annular and axially aligned, winding 40 being wound on the main core 12 only, and primary winding 40 being wound on all three cores. Although my prior patent does not show the feedback control windings 66 and 68, it should be understood that these windings are toroidally wound on their respective cores either adjacent to the control windings 18 and 20, whereby each winding surrounds a portion of its associated core, or, where both control windings are wound concurrently, with alternating turns around the full circumference of the core. Another possibility would be to arrange the control windings concentrically, so that the external control and the feedback control windings on each core would form toroids around their respective cores, one winding surrounding the other.

As illustrated in my prior patent, secondary winding 32 is toroidally wound on the main core 12 for isolation from the direct current control flux induced in the auxiliary cores. Again, the feedback supply winding 50 is not illustrated in my prior patent, but it will be understood that this winding may be wound on the main core adjacent to the secondary winding 32, with each winding thus taking up a portion of the circumference of the main core. Alternatively, the two windings may be wound...
together with alternating turns, or they may be wound concentrically; in either case, both windings would extend around the full circumference of the core. The primary winding 40 is inductively coupled to all three cores, with each turn of this winding passing around, or surrounding, all three cores and their respective secondary, feedback and control windings.

The feedback supply winding 50, which may provide an output of up to 40 amperes in one embodiment of the invention, is normally designed with a sufficient number of turns so that its output can be adjusted by means of potentiometer 52 to supply approximately 85 percent of the desired saturation. When properly arranged, the control windings 18 and 20 will provide the remaining 15 percent of the control power, permitting a substantial reduction in the capacity and size of the usual external control source. With this proportion, the external control source will then provide a Vernier control of the transformer with the main controlling effect being derived from the feedback circuit. It has been found that about 85 percent is the maximum amount of control power that should be provided by the feedback windings. If additional feedback control is provided, the external control will not have much effect upon the operation of the system. In such a case, the load current will go to full power and remain there; the external control source is ineffective to decrease the power output of the variable reactance transformer. However, at 85 percent the external control power source is capable of effectively regulating the system.

The operation of the basic variable reactance transformer is set forth in some detail in my prior patent, above-mentioned, which describes the manner in which the degree of saturation of the auxiliary cores affects the output appearing on the secondary winding 32. As noted in that patent, by making the DC external control source variable, any desired degree of saturation may be attained in cores 14 and 16 and varying amounts of energy will thus be available to drive the main core 12 and the secondary winding 32. Whereas the entire control power in the prior device was obtained from the external control source, the present invention is distinct in that it is made responsive to the load impedance through the use of the described feedback circuit. Thus, when the load impedance is at a low value, there tends to be a high current in the output winding 32 of the variable reactance transformer and, simultaneously, a low feedback current in feedback supply winding 50. The feedback current in winding 50 is converted to a direct current and is applied to the control cores 14 and 16, decreasing the saturation of the control cores and increasing the impedance of the variable reactance transformer, thus reducing the output load current. As the impedance of the load increases, the feedback current induced in winding 50 decreases, causing the impedance of the auxiliary cores to decrease. This decrease in transformer impedance permits the load current to increase to compensate for the increase in load. As the load impedance continues to go up, the feedback current continues to increase, reducing further the impedance of the auxiliary cores, permitting the load current to increase until the system reaches full power when the load impedance is at the design level. Thus, the variable reactance transformer senses and responds to the load impedance to control the load current and prevent the current from exceeding the desired level.

In the embodiment of the invention which has been described herein, with an electric resistance furnace as the load for the variable reactance transformer, which load would be approximately 0.05 ohm at maximum temperature, and with the furnace at its maximum temperature, the system may be adjusted by setting the potentiometer 52 to provide approximately 50 percent of its available feedback current. The external control source 24 is then set to its maximum control level, and the potentiometer 52 is adjusted to obtain the maximum design output from the secondary winding 32. Under this operating condition, the reduction of the external control current should decrease control core saturation enough to cause a proportionate decrease in the output current in the secondary winding 32. If too much feedback current is present, the feedback winding will overpower the control circuit and reduction of the output from magnetic amplifier 24 will not affect the output appearing across terminals 34 and 36. As has been noted, the normal proportioning of control would find the feedback control winding supplying 85 percent of the control energy with the remaining 15 percent being supplied from the magnetic amplifier 24. However, the exact proportion of feedback to external control is a function of the exact load impedance.

Once the system has been properly adjusted for its load, subsequent applications of the variable impedance load will be handled automatically by the system, with the initial current to a low impedance being held to a relatively low value and gradually increasing to the desired level as the impedance increase to its design value. This operation is fully automatic and is a distinct improvement over prior art methods of controlling such loads. Although the system has been described in, and particularly useful with, an electric resistance furnace, and specific current and load resistance values have been given, it will be apparent that other variable impedance loads may be used with this system and the load current similarly regulated at the selected levels.

Not only does the variable reactance transformer permit a gradual increase in load current to protect both the load and the power input source, but the transformer system also acts to protect itself against fault conditions in the load. As has been explained, the feedback arrangement of the present invention is adapted to respond to a fault condition such as a short circuit sufficiently quickly to prevent damage to the system. For example, if the normal full load secondary current is 1,000 amperes, it would be expected that a short circuit in the load would produce a much higher current condition. However, the tendency toward a high current condition caused by a short circuit immediately decreases the feeding current and thus decreases the impedance of the transformer. It has been found that with a transformer of the present type, the maximum available secondary current under short circuit conditions would be approximately 300 amperes with the full two ampere control current from magnetic amplifier 24. With the direct current from the magnetic amplifier being reduced to zero, the short circuit current through the load would be less than 400 amperes. Since the system is designed to handle a secondary current of 1,000 amperes, it will cause no damage to the system.

Thus, there has been described a variable reactance transformer having an improved response time, power factor and efficiency which, by reason of the use of feedback control circuitry, is responsive to load impedance and permits a simplified, and thus less expensive, low power external control source. Many variations and modifications of the inventive concept herein described will be apparent to those skilled in the art, and it is therefore desired that the foregoing description be taken as illustrative.

I claim:

1. A variable reactance transformer having a main core and a pair of auxiliary cores located adjacent thereto, a secondary winding wound on said main core, an external control winding wound on each of said auxiliary cores, said external control windings being connected in series opposition, and a primary winding surrounding said main and auxiliary cores, the improvement comprising: a variable impedance load connected across said secondary winding, feedback circuit means responsive to the impedance of said load to control the current supplied to said load by said secondary winding, said feedback
circuit means including a feedback supply winding wound on said main core, converter means for converting alternating feedback current to direct feedback current, and a feedback control winding wound on each of said auxiliary cores, said feedback control windings being connected to said converter means in series opposition and being wound on said auxiliary cores to aid the corresponding external control windings, whereby a reduced load impedance produces a reduced feedback current and an increased reactance of said variable reactance transformer to reduce said current supplied to said load.

2. The variable reactance transformer of claim 1, wherein said feedback circuit further includes variable resistance means connected to said feedback supply winding to permit adjustment of said feedback current.

3. The variable reactance transformer of claim 2, wherein said converter means includes a feedback transformer and rectifier means for converting alternating feedback current from said feedback supply winding to direct feedback current.

4. The variable reactance transformer of claim 1, further including a source of external control current for said external control windings, said feedback circuit means providing approximately 85 percent and said source of external control current supplying the remainder of the total control current required by said variable reactance transformer.

5. The variable reactance transformer of claim 3, wherein said source of external control current is variable to regulate the reactance of said auxiliary cores and thus to provide a Vernier control of the current supplied to said load.

6. In a variable reactance transformer having control means responsive to load impedance, a main core and first and second auxiliary control cores; a secondary winding wound on said main core; variable impedance load means connected across said secondary winding; a feedback supply winding wound on said main core; first and second external control windings and first and second feedback control windings wound on said first and second auxiliary cores, respectively; an external variable source of DC control current, said external control windings being connected in series opposition across said external source of control current; rectifier means; said first and second feedback control windings being connected in series opposition through said rectifier means to said feedback supply winding; a source of power; and a primary winding connected across said source of power and wound on said main core and said first and second auxiliary cores, whereby the feedback current induced in said feedback supply winding is proportional to the impedance of said load, the feedback current and the external control current serving to vary the reactance of said first and second auxiliary cores to regulate the power supplied through said variable reactance transformer to said load.

7. The variable reactance transformer of claim 6, further including variable impedance means in circuit with said feedback supply winding to permit adjustment of the feedback current level, whereby said feedback current provides approximately 85% and said external control current provides approximately 15 percent of the total control energy supplied to said first and second auxiliary cores.

8. The variable reactance transformer of claim 6, wherein said load means is an electric furnace resistance element the impedance of which varies with temperature.

References Cited

UNITED STATES PATENTS

2,586,657 2/1952 Holt 323—56 X
2,870,397 1/1959 Kelley 323—56
3,123,764 3/1964 Patton 323—56

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