

MOTOR CONTROL SYSTEM AND COMPONENTS THEREOFBackground of the Invention

This invention relates generally to a motor control system and it also relates generally to individual components of the system. More particularly, but not by way of limitation, the invention relates to a transformer, a unitary housing, and a double interlock mechanism, all of which are suitable for use in an apparatus for operating a three-phase motor to drive a submersible pump. The present invention is also more particularly directed to a system and method for controlling the energization of a transformer's secondary winding circuit to which a three-phase motor is connected.

Submersible pumps are used, for example, in oil wells at remote locations. Three-phase electric motors are typically used to drive these pumps. Such a motor is rated for a nominal line-to-voltage which must be provided within a specified tolerance for the motor to work. This voltage is typically provided from an electric utility through a transformer and motor controller to provide the suitable voltage and control to operate the motor as desired.

Transformers and motor controllers which have been used in the past have been separate products. That is, the transformer has had its own housing and the motor controller has had its own housing. External connections between the two are needed to have

the two work together. Although having two separate units might allow more flexibility in choosing components for a particular application, it has the possible shortcomings of increased price for two rather than one unit and of increased costs for shipping and warehousing. Two separate units would also likely require more space at the location where they are to be used. Therefore, there is the need for a unitary power supply package wherein a transformer and motor controller are interconnected and housed in a single compact unit which can be readily transported to remote locations and easily connected to a source of electricity and a load, such as a three-phase electric motor driving a submersible pump.

To facilitate the use of such a unitary power supply package at a remote location, it should be designed so that a human operator on the ground can have access to at least some internal parts should they need to be repaired or checked in the field. Ground-level access should also be provided so that the operator can readily select a desired output suitable for the load to be energized and readily control a master on/off switch of the power supply package. Access to at least high voltage components should, however, be prevented by automatic interlocks which operate when the master switch is "on."

For safety and economy, the transformer within the power supply package should be designed to provide all needed output and operating voltages, and it should also be designed to shield

against electrostatically and magnetically coupled transients. Appropriate switching and fusing regardless of the desired output should also be provided.

Such a unitary power supply package should also include a readily transportable housing which accommodates all the other needs mentioned above.

Another feature of the prior transformer and motor controller systems is that the motor controller package includes an air-insulated master power switch, a combined current limiting and load sensing fuse and an electrically operated start-stop contactor switch mechanism connected in series. This places all these components on one side of the transformer.

The disadvantage of the typical master power switch is that it is expensive. It is expensive because it must be constructed to operate safely within its air-insulated environment. Further, the master power switch is typically not used as a complete safety disconnect because it is not constructed to disconnect safely when the motor is energized; rather it is used to isolate the downstream components after the contactor switch mechanism has disconnected the motor. An air-insulated power switch adequate to break the load directly would be even more expensive.

A typical combined current limiting and load sensing fuse used in prior motor controllers is also relatively expensive; therefore, everytime a short-circuit fault or other current overload condition clears the fuse, it must be replaced with a

similarly expensive fuse. Another disadvantage of using the fuse in the prior manner is that it cannot be rated for all the transformer outputs which might be available.

In view of these additional disadvantages, there is
5 the need for a system which incorporates a relatively inexpensive, truly emergency safety master power switch which is directly manually operable without the aid of any tools to break a fully loaded circuit. There is also the need for the system to utilize fusing which is relatively
10 inexpensive and which is fully effective to protect the system upstream of a short-circuit fault regardless of a selected transformer output.

The present invention overcomes at least some of the above-noted and other shortcomings of the prior art and
15 meets aforementioned needs by providing a novel and improved motor control system and components thereof.

According to the present invention there is provided a system for operating a three-phase motor, comprising:

a transformer including a three-phase primary winding
20 and a three-phase secondary winding, said transformer providing transformation of a three-phase input voltage to a three-phase motor energizing voltage;

secondary winding circuit means for connecting a three-phase motor to said secondary winding, said secondary
25 winding circuit means including motor control means, connected to said secondary winding to receive said three-phase motor energizing voltage from said transformer, for controlling the application of said three-phase motor energizing voltage from said secondary winding to a
30 connected three-phase motor; and

primary winding circuit means for connecting to a three-phase power source and for controlling whether current flows through said three-phase primary winding from a connected three-phase power source, said primary winding circuit means including master on/off switch means, 5 connected to and located in a common housing with said primary winding of said transformer and responsive to direct manual operation with means for manual operation located within reach of a person adjacent said motor control means, for selectably energizing or de-energizing 10 said transformer so that said three-phase motor energizing voltage is thereby selectably provided or not provided to said motor control means.

The present invention may further provide a unitary 15 power supply package with the interconnected transformer and motor controller combined in a single housing which can be readily transported to remote locations and easily connected to a source of electricity and load, such as the three-phase motor driving a submersible pump.

20 The housing is constructed to be placed on the ground during use so that a human operator can readily access function switches and at least some internal components and observe condition indicators. Access to such internal parts and to some function switches is limited by a double 25 interlocking mechanism which is activated whenever the package is operated to provide power to a load.

The transformer of the package may be filtered and double shielded to protect against magnetically and electrostatically coupled transients. This is achieved in 30 part by an integral tertiary winding which also provides a suitable output level to operate the motor controller;

therefore, separate transformers are not needed in the power supply package. Direct lightning strikes to the secondary circuit of the power supply package should be eliminated because the secondary circuit is completely
5 enclosed in solidly grounded metal surfaces of the housing and armoured cable.

Both current limiting and load sensing fuses may be connected serially to each phase of the primary of the transformer. The switch and fuses are, in the preferred
10 embodiment, contained within an oil-filled chamber of the housing wherein the transformer windings are also located. Due to this oil-insulated construction the switch is relatively inexpensive, and yet it can provide a true emergency safety disconnect because it can be directly
15 manually operated without any tools to break the circuit on the primary side of the transformer even when a load connected to the secondary of the transformer is operating. The fuses are selected and used so that the load sensing fuses, which are more likely to clear than the current
20 limiting fuses, are relatively inexpensive, can be readily replaced and are fully effective to protect the system regardless of the output voltage of the transformer.

Thus, the present invention has advantages pertaining to safety, economy, compactness and reliability.

Therefore, from the foregoing, it is a general object of the present invention to provide a novel and improved motor control system. It is also a general object of the present invention to provide a novel and improved transformer and a novel and improved transportable containment means. In their preferred embodiments, these components are adapted for use in the inventive motor control system, but they are not limited to such use. Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art when the following description of the preferred embodiment is read in conjunction with the accompanying drawings.

Brief Description of the Drawings

FIG. 1 is a schematic circuit diagram of transformer and motor controller portions of the preferred embodiment of the motor control system of the present invention.

FIG. 1A is a block diagram of a winding configuration for one

phase of the preferred embodiment of the transformer within the transformer portion of the motor control system.

5 FIG. 2 is a side elevational view of the preferred embodiment of a transportable containment means of the motor control system.

FIG. 3 is a plan view of the transportable containment means.

FIG. 4 is an end elevational view of the transportable containment means.

10 FIG. 5 is another end elevational view of the transportable containment means.

15 FIG. 6 is an elevational view of an interior wall of the transportable containment means, to which wall components of a high voltage section of the motor controller portion of the motor control system are mounted.

FIG. 7 is an enlarged partial side elevational view showing the preferred embodiment of a double interlocking means of the present invention in one operative position.

20 FIG. 7A is an end sectional view taken along lines 7A-7A shown in FIG. 7.

FIG. 8 is an enlarged partial side elevational view of the preferred embodiment of the double interlocking means of the present invention in another operative position.

25 FIG. 9 is an enlarged partial side elevational view showing the double interlocking means in the position shown in FIG. 8,

but with a cover moved to an open position and the handle of the double interlocking means locked in its illustrated position.

FIG. 10 is an enlarged partial elevational view of the preferred embodiment of a latch of the double interlocking means shown in a latching position.

FIG. 11 is an enlarged partial elevational view of the latch shown in an unlatching position.

FIG. 12 is a side view of a switch operating connector block of the double interlocking means.

FIG. 13 is an end view of the connector block.

FIG. 14 is an opposite end view of the connector block.

FIG. 15 is another side view of the connector block.

FIG. 16 is a sectional view of the connector block taken along line 16-16 shown in FIG. 15.

FIG. 17 is a side view of a door latch operating mechanism of the double interlocking means.

FIG. 18 is an end view of the door latch operating mechanism.

FIG. 19 is an opposite end view of the door latch operating mechanism.

FIG. 20 is another side view of the door latch operating mechanism.

FIG. 21 is a sectional view of the door latch operating mechanism taken along line 21-21 shown in FIG. 17.

FIG. 22 is a side view of a switch handle locking block of the double interlock means.

FIG. 23 is an end view of the switch handle locking block.

FIG. 24 is another side view of the switch handle locking block.

FIG. 25 is a side elevational view of a retaining plate providing a locking tab for the cover of the transportable containment means.

FIG. 26 is an end view of the retaining plate.

FIG. 27 is another end view of the retaining plate.

Detailed Description of Preferred Embodiment

The preferred embodiment of the motor control system of the present invention is schematically shown in FIG. 1 as including a transformer circuit 2 and a motor controller circuit comprising a high voltage section 4a and a low voltage section 4b. These are enclosed within a transportable containment apparatus represented by the dot-dash line 6.

The input of the transformer circuit 2 is adapted to be connected to a suitable power source, such as a three-phase electric utility power source 8. The source 8 typically provides a nominal line-to-line voltage higher than the tolerable line-to-line voltage of a load to be energized with the present invention. In the preferred embodiment described herein the power source 8 provides a substantially constant a.c. (alternating current) voltage from within the range of about 4160 Vac to about 34500 Vac ("substantially constant" encompassing fluctuations from the nominal voltage in a conventional voltage source). This is the

input voltage to the transformer circuit 2. The present invention lowers this voltage and controls its application to the load, a three-phase motor 10 connected, for instance, to a submersible pump

12. The windings of the motor 10 are connected to outputs A, B, C of the high voltage section 4a of the motor controller for the use illustrated in FIG. 1.

In a contemplated particular application, the motor control system would be placed at the base of a typical riser pole which supports the three-phase power lines of the utility power source 8. Cables from the source 8 would be run down the riser pole and connected to the inputs H1, H2, H3 of the transformer circuit 2. From the outputs A, B, C of the high voltage section 4a, cables would be extended to a vented junction box from which cables would extend to connect to the motor 10.

Referring to FIG. 1, the transformer circuit 2 includes a transformer 14. The transformer 14, which is a step-down transformer that provides the only voltage level conversion between the power source 8 and the motor in the illustrated embodiment, includes three primary windings 16a, 16b, 16c and three secondary windings 18a, 18b, 18c. The windings 16, 18 are conventional. The secondary windings 18 are switchably interconnected by a suitable output selection switch 20, such as one used in transformers manufactured by Southwest Electric Company of Oklahoma City. In a particular embodiment, the switch 20 has two exterior handles 22, 24 (FIGS. 2 and 9) mounted on shafts passing through the containment apparatus 6. Rotating the handles 22, 24 selects

different taps from the windings 18 for providing different outputs. The handles 22, 24 are manually operated by a person standing on the ground adjacent the motor control apparatus. The switch 20 of the preferred embodiment provides a wide voltage range with all outputs being full kVA rated. The secondary of the transformer 14 is dedicated to a single load, namely the electrical submersible pump motor 10 in the preferred embodiment.

The thus selected portions of the windings 18 are then connected in either a delta or a wye connection by means of a switch 26 which has a handle 28 (FIGS. 2 and 9) mounted on a shaft of the switch 26 passing through the containment apparatus 6. An example of a suitable switch 26 is the RTE Components (Pewaukee, Wisconsin) 150A externally operated Series Multiple Switch.

Transformer 14 also includes tertiary windings 30a, 30b, 30c. The primary windings 16, the secondary windings 18 and the tertiary windings 30 are all inductively coupled within respective groups to provide a three-phase transformer. Each phase of the preferred embodiment is wound in the manner depicted in FIG. 1A wherein a core leg 32a supports the secondary winding 18a, the tertiary winding 30a and the primary winding 16a. It is an important feature of the preferred embodiment that these windings are in the configuration shown in FIG. 1A with the tertiary winding 30a radially in between the primary winding 16a and the secondary winding 18a. A conventional electrostatic shield 34a is

disposed between the primary winding 16a and the tertiary winding 30a. Whether the secondary is innermost and the primary outermost as drawn in FIG. 1A, or vice versa, is immaterial; what is important is that the tertiary is radially in between the two and that the electrostatic shield 34 (if used) is radially in between the tertiary and the primary. These same relationships for the tertiary and electrostatic shield should be retained if additional radially disposed windings are used within a winding group on a core leg. Each of the other two phases is similarly constructed as is apparent from FIG. 1. The leg 32a and the legs 32b, 32c (FIG. 2) in the preferred embodiment are part of an overall iron core of a type known in the art.

The tertiary windings 30 provide electrostatic shielding so that the transformer 14 is double-shielded. This is achieved by grounding one end of each of the windings 30a, 30b, 30c as shown in FIG. 1 (alternatively, one tertiary winding could be grounded and the other tertiary windings could be connected to the grounded winding, or to both ground and the grounded winding). This places these common ends in a common ground connection with the conventional electrostatic shield 34. Thus, both the electrostatic shield 34 and the tertiary windings 30 filter electrostatically induced transients; therefore, they need to be disposed between the primary and secondary windings. So that each tertiary 30 can itself be shielded, the respective electrostatic shield 34 needs to be between the primary and the

tertiary. A different degree of electrostatic shielding can be obtained by the tertiary windings 30 depending upon the particular winding configuration and axial length. In general, these should be such that the electrostatic induction between the primary windings 16 and the secondary windings 18 is measurably reduced. To maximize the shielding, the axial length of each tertiary winding should be at least as long as the longer of the respective primary winding or secondary winding.

The tertiary windings 30 also filter magnetically induced transients in conjunction with capacitors 36, 38, 40 physically located within the high voltage section 4a of the motor controller but electrically connected to the tertiary windings 30. The capacitors 36, 38, 40 shown in FIG. 1 are connected to the ends of the tertiary windings 30 opposite the ends thereof connected to electrical ground. The capacitance preferably is such that the magnitude of transient voltages induced into the tertiary and secondary windings by lightning or switching spikes imposed onto the primary windings is measurably reduced.

A third function of the tertiary windings 30 is to provide control power and metering voltages to the controller section. This is illustrated in FIG. 1 by the connections of the tertiary windings 30 to the low voltage section 4b of the motor control circuit.

In a particular embodiment, each of the tertiary windings 30 is implemented by a respective layer of a 0.48 cm (3/16 inch) wide by 0.16cm (1/16 inch) thick rectangular

wire spirally wound on the respective electrostatic shield

14 with 0.48cm (3/16 inch) spacing between turns.

Within each phase of the transformer 14, each of the respective windings and the electrostatic shield is electrically insulated by being wrapped on kraft paper or other suitable insulating substrate known in the art.

The transformer circuit 2 also includes a primary winding circuit which connects the primary windings 16 to the power source 8 when the power source is connected to the high voltage terminals H1, H2, H3. This circuit includes a primary switch 42 used for selectably energizing and de-energizing the transformer 14 and the motor controller from the power source 8. The switch of the preferred embodiment is intended to be operated manually by a person standing on the ground adjacent where the motor control system is located. This operation is direct, i.e., without the aid of any tools, such as a hot stick. The switch 42 should be rated at least for interrupting full load current. The switch 42 is a true emergency safety disconnect switch which can be directly operated by a person to break the current conductive path between a connected power source and the primary windings 16. When the switch 42 makes or completes the current conductive path, the input a.c. voltage is applied to the primary windings 16 so that an induced a.c. output voltage is provided on the secondary windings 18. This causes an output current to flow in a secondary winding circuit connected to the secondary windings

18 if the secondary winding circuit is completed as subsequently
described. The resulting input current which flows through the
primary side of the transformer 14 is proportional to such output
current. The switch 42 is preferably one which is oil-insulated
5 so that it is relatively inexpensive despite being able to break
full load current. Any suitable type switch can be used, such as
a RTE Components two-position Loadbreak/Loadmake stored energy
type switch. This is a three-phase switch with one pole per
phase connected in series between the source 8 and a respective
10 primary winding 16 of the transformer 14. The operating mecha-
nism of the switch 42 includes a shaft 43 (FIG. 7A) which extends
through the containment apparatus 6. This pass-through of the
containment apparatus 6 and the others referred to herein are
made fluid-tight by suitable sealing members as would be readily
15 known in the art.

Connected in series with the respective section of the switch
42 are load sensing fuses 44a, 44b, 44c and current limiting
fuses 46a, 46b, 46c. The switch 42 and the fuses 44, 46 can be
in any order within the series configuration.

20 The fuses 44 are preferably field replaceable, such as by
being contained within draw-out mechanisms that penetrate the
side of the containment apparatus 6. Each fuse 44 includes a
fuse carrier 48 having terminals connected in the electrical
series as represented in FIG. 1. The fuse carrier 48 is also
25 connected to the containment apparatus 6 so that an opening of

the fuse carrier communicates outside the containment apparatus 6 (FIGS. 2 and 9). A fuse member 50 is releasably connected within the fuse carrier 48 and is replaceable through the opening of the fuse carrier 48. A particular type of fuse which can be used is the RTE Components Bay-O-Net Fuse Assembly with the RTE Components Dual Sensing Bay-O-Net Fuse Link.

The fuses 44 are relatively inexpensive because they provide a lower current interrupting capacity which does not have to withstand as high a current as the fuses 46. The fuses 44 are capable of interrupting a fault current with a magnitude limited solely by the sum of the internal impedance of the power source 8 added to the impedance of the transformer 14 with the secondary windings short-circuited. Stated another way, the fuses 44 stop current flow within the primary winding circuit in response to current flowing therethrough exceeding a predetermined level in response to a short-circuit fault in the secondary windings 18, the secondary winding circuit, or a motor connected to the secondary winding circuit. That is, when a short-circuit fault on the secondary side of the transformer 14 occurs, the magnitude of the output current increases and the magnitude of the input current increases in response. When the increase of the input current reaches a predetermined level, the fuses 44 clear. The predetermined level corresponds to the selected rating of the fuses 44. When the fuses clear, the transformer and the secondary winding circuit are de-energized. This protects the portion of the system upstream of the fault (towards the power source). The

uses 44 clear before the current limiting fuses 46 except when the current exceeds the interrupting capacity of the fuses 44. Such greater fault currents are cleared by the fuses 46.

The current limiting fuses 46 are disposed inside the containment apparatus 6 so that they are not typically field replaceable. The fuses 46 are for clearing the power lines when the transformer 14 fails. More generally, the fuses 46 are capable of interrupting fault currents with a magnitude limited solely by the internal impedance of the power source 8. An example of a suitable fuse 46 is the RTE Components ELSP Current-Limiting Backup Fuse.

Although not shown in the drawing, the transformer circuit can also include suitable conventional arresters to shunt each line to ground in a conventional manner.

The motor controller components of the motor control sections 4a, 4b are conventional. Typically, the particular motor controller would be specified by the user to coordinate with other equipment. An example of a typical controller is a VORTEX (Trade Mark) brand motor controller.

Referring to FIG. 1, the high voltage section 4a includes a vacuum contactor 52 which is electrically operable to connect or disconnect the outputs from the switch 26 to the terminals A, B, C (and the motor 10 when connected thereto). The outputs from the switch 26 are provided to the high voltage section 4a through terminals X1, X2, X3. In the preferred embodiment the output

includes a substantially constant a.c. voltage within the range of about 460 Vac to about 4160 Vac. There is one contactor pole per phase in series between the secondary of the transformer 14 and the output terminals A, B, C. The contactor 52 is an electrically operated start-stop switch which turns a motor connected to the terminals A, B, C on or off when the output voltage is available at the contactor poles connected to the selected secondary winding sections through the switches 20, 26 and the terminals X1, X2, X3. These connected components comprise the secondary winding circuit by which the motor 10 is connected to the secondary of the transformer 14. The wiring, such as cables, used to connect the motor 10 to the terminals can also be part of the secondary winding circuit. When the contactor 52 is in a conductive state, and the motor 10 is connected, the entire secondary circuit is completed so that if there is output voltage it is applied to the motor and output current flows through the secondary winding, the secondary winding circuit and the motor (when reference is made to a voltage being applied or the like from one point to another, this encompasses any voltage drops across intervening circuitry). When the contactor 52 is in a non-conductive state, the motor 10 is not energized.

The high voltage section 4a also includes three current transformers 54a, 54b, 54c which sense current through the respective phase output line to provide control signals to a solid state logic controller 56 in the low voltage section 4b.

5 The controller 56 also receives sensing inputs, as well as energizing electricity, from the tertiary windings 30. The controller 56 is operated by start and h-o-a (hand-off-automatic) switches 58, 60, respectively. Indicator lights 62 signal operating conditions in a known manner. A chart recorder/ammeter 64 is also included in the low voltage section 4b, as is a convenience outlet 66.

10 Although the transformer 14 of the preferred embodiment and its primary side switch 42, with or without fuses 44 or 46, in combination with a secondary-connected motor controller are each novel, the motor controller components of the high voltage section 4a and the low voltage section 4b of the motor control circuit are conventional. It is to be noted, however, that housing all these components of both the transformer circuit 2 and the motor controller circuit 4 within the single containment apparatus 6 is also novel.

15 Referring to FIGS. 2-6, the transportable containment apparatus 6 of the preferred embodiment includes a single, multicompartment enclosure 68 mounted on a skid 70. The skid 70 provides a base for supporting the housing on the ground. The apparatus 6 can be positioned before or after the external connection cables have been installed at the site where the present invention is to be used.

20 The enclosure 68 includes a compartment 72 for receiving the components of the transformer circuit 2 shown in FIG. 1. These

include the transformer 14 (except for the capacitors 36, 38, 40), the primary switch 42 and the fuses 44, 46. In the preferred embodiment these components are immersed within a volume of liquid, such as a suitable oil known in the art. The surface of the liquid is identified in FIG. 2 by the reference numeral 74. This surface is below the access openings of the fuse carriers 48 of the field replaceable fuses 44. The portion of each fuse carrier 48 into which its replaceable fuse element 50 is connected is, however, below the surface of the liquid, as are the other components of the transformer circuit 2 which are within the compartment 72.

The enclosure 68 includes a compartment 76 in which the capacitors 36, 38, 40 and the components of the motor control sections 4a, 4b are located. At one end of the compartment 76 there is a door 78. There is a door 80 located within the interior of the compartment 76 to divide the compartment 76 into two chambers 82, 84. The components of the low voltage section 4b shown in FIG. 1 are located in the outer chamber 82 and on the door 78, and the capacitors 36, 38, 40 and the components of the high voltage section 4a shown in FIG. 1 are located within the inner chamber 84.

The enclosure 68 includes a compartment 86 containing the high voltage terminals H1, H2, H3 (FIG. 1) to which the power source 8 connects. A door 88 is connected at one end of the compartment 86.

The compartments 72, 76, 86 are defined by side walls 90, 92, end walls 94, 96, and the doors 78, 88. These are also defined by lower plate 100, upper plates 102, 104 and top 106.

Side walls 90, 92 are connected to the base 70 and spaced from each other transversely across the width of the base 70. These side walls can be continuous or defined by individual, but interconnected, plates (such as by welding). They extend perpendicularly from the base 70.

The end walls 94, 96 are connected to the base 70 and to the side walls 90, 92 so that the first compartment 72 includes the end walls 94, 96 and the portions of the side walls 90, 92 in between the end walls 94, 96 and so that the compartment 76 includes the end wall 94 and portions of the side walls 90, 92 extending beyond the end wall 94 away from the compartment 72.

Thus, in the preferred embodiment the compartments 72, 76 are adjacent each other with the common intervening wall 94. The compartment 72 includes a floor provided by the top of the base 70. The compartment 72 is covered at the top by the removable top 106 bolted to a flange extending around the respective side walls and end walls. The compartment 76 is completed by the lower plate 100 and the upper plate 102 and the door 78 extending between the side walls 90, 92 at the end of the compartment 76 opposite the end wall 94. The door 80 within the compartment 76 is disposed between the side walls 90, 92 intermediate the end wall 94 and the door 78. Within the inner chamber 84 of the com-

partment 76, the capacitors 36, 38, 40 and the components of the high voltage section 4a shown in FIG. 1 are mounted on the end wall 94 as shown in FIG. 6.

5 The compartment 86 is defined by the end wall 96 which is shared in common with the compartment 72. The compartment 86 is also defined by the ends of the side walls 90, 92 extending beyond the end wall 96 away from the compartment 72. These portions of the side walls 90, 92 also extend downward to ground level at the bottom of the base 70. The compartment 86 is
10 further defined by the upper plate 104. The end of the compartment 86 opposite the end wall 96 is closed by the door 88. The bottom of the compartment 86 is left open so that underground cables, for example, can be received into the compartment without passing through the door 88.

15 Other features of the containment housing 6 are lifting lugs 108, a grounding connector 110 and cooling panels 112. The cooling panels 112 are vertical flat plates connected to the side wall 92. As shown in FIG. 5, associated with the end wall 96 of the enclosure 68 above the compartment 86 is a pressure relief
20 valve 114 for relieving excessive pressure from within the compartment 72. Also associated with the end wall 96 above the compartment 86 is a fill plug 116 through which the oil or other suitable liquid is flowed into the compartment 72. A drain valve 118 (FIG. 4) allows the liquid to be drained. An oil level gauge
25 120 and an oil temperature gauge 122 on the side wall 90 monitor

these conditions of the liquid inside the compartment 72. A name plate 123 is also mounted on the side wall 90.

Also associated with the side wall 90 is a cover 124. The cover 124 is connected to the enclosure 68 so that the cover 124 is movable between an open position (FIG. 9), wherein the output selection switch handles 22, 24, the delta-wye switch handle 28 and the fuse carriers 48a, 48b, 48c are accessible, and a closed position (FIGS. 2, 7 and 8), wherein these components mounted through ports in the side wall 90 are inaccessible. In the preferred embodiment the cover 124 is hinged to a support plate 126 welded or otherwise suitably connected to the outside of the side wall 90 intermediate the end walls 94, 96. For a use to be described further hereinbelow, the cover 124 includes a retaining plate 128 connected along the edge of the cover 124 opposite the edge connected to the support plate 126. In the preferred embodiment the retaining plate 128 has the construction shown in FIGS. 25-27. This includes a tongue portion 130 at the top of which a support shoulder 132 is connected so that it extends perpendicularly outward from the tongue portion 130. The portion 130 is beveled, notched or otherwise configured to provide both an end to be retained by a retaining member (subsequently described) when the cover 124 is to be locked in its closed position and a space to allow passage of the tongue portion 130 past the retaining member when the cover 124 is permitted to be opened. A tab 134 extends from the support shoulder 132. The tab 134 has a

hole 136 for receiving a screw or bolt 137 or other suitable mechanism which can be adjusted inwardly or outwardly through the hole 136 to engage a threaded nut 139 fixed to the side wall 90 for stabilizing the cover 124 in its closed position so that the cover 124 does not rattle. When the cover 124 is in its closed position, the retaining plate 128 is engaged by part of a double interlock mechanism 138. The mechanism 138 both locks the cover 124 in its closed position and locks the door 80 in its closed position in response to the primary switch 42 within the transformer circuit 2 being switched to its energizing position.

The double interlock mechanism 138 generally depicted in FIG. 2 and more clearly shown in FIGS. 7-11 is connected to the primary switch 42. When the switch 42 is manually operated by a person on the ground adjacent the containment apparatus 6, the double interlock mechanism 138 automatically mechanically interlocks or releases the cover 124 and the door 80. Interlock occurs when the switch 42 is switched to its energizing position, and release occurs when the switch 42 is moved to its de-energizing position. When the switch 42 is in its circuit energizing position, the closed cover 124 and the closed door 80 are locked to prohibit access to the fuses 44 and voltage adjusting switches 20, 26 behind the cover 24 and the high voltage section 4a components behind the door 80.

Referring particularly to FIGS. 10 and 11, the double interlock mechanism 138 includes a latch 140 which is movable

between a position to engage the door 80 (FIG. 10) and a position to disengage the door 80 (FIG. 11). The latch 140 is pivotally connected at one end on the inside of the side wall 90 within the compartment 76. A pin 142 prevents the latch 140 from pivoting backward over the center of pivotation. The latch 140 engages a catch member 144 connected to the door 80 when the latch 140 is in its door engaging position and the door 80 is closed as illustrated in FIG. 10. In this position, the door 80 is held in its closed position until the latch 140 is moved to its disengaging position shown in FIG. 11. Disengagement can occur in the preferred embodiment either by operation of the double interlock mechanism 138 or by manually lifting up on the latch 140 through a small opening (not shown) provided in the door 80.

The double interlock mechanism 138 also includes manual operating means for concurrently operating the primary switch 42 and the latch 140 so that the latch 140 is in its door-engaging position when the primary switch 42 is operated for energizing the primary winding 16 of the transformer 14 and so that the latch 140 is in its door-disengaging position when the primary switch 42 is operated to its de-energizing position. The manual operating means also concurrently prevents the cover 124 from being moved from its closed position to its open position when the cover 124 is in its closed position and the primary switch 42 is in its energizing position. This operating means is disposed on the exterior of the housing 6 in connection with the side wall

90.

The manual operating means includes operating means for operating the latch 140. The operating means is mounted through the side wall 90 so that there is a portion of the operating means inside the compartment 76 and another portion of the operating means outside the housing 6. The operating means includes a latch movement member 146 rotatably mounted to the side wall 90 in engagement with the latch 140. The preferred embodiment of the latch movement member 146 is shown in FIGS. 17-21. The member 146 shown in these drawings includes a shaft 148 on the exterior end of which is mounted a pulley 150. The interior end of the shaft 148 includes a half cylindrical portion 152 acting as a cam upon which the latch 140 rides as best illustrated in FIGS. 10 and 11. Grooves 154, 156 on the shaft 148 carry a sealing ring and a retaining ring for providing a fluid tight seal where the shaft 148 passes through the side wall 90. The pulley 150 has a threaded cavity 158 defined therein for receiving a screw to retain a drive belt on the pulley 150 as subsequently described hereinbelow.

The manual operating means also includes a handle 160 connected outside the housing 6 to the switch 42. In particular, the handle 160 is connected to the shaft 43 of the switch 42 passing through the side wall 90. This connection is made through a drive means for coupling the handle 160 to the pulley 150 of the latch movement member 146 so that operative movement

of the handle 160 actuates the operating means to operate the
latch 140. The drive means includes a connector 162 for con-
necting the handle 160 to the shaft 43 of the switch 42 outside
the housing 6 so that the handle 160 is movable between a switch
energizing position (FIG. 7) and a switch de-energizing position
5 (FIGS. 8 and 9). The drive means also includes coupling means
for coupling the connector 162 and the latch movement member 146
so that the latch movement member 146 moves synchronously with
the shaft 43 of the switch 42 in response to operation of the
10 handle 160.

Referring to FIGS. 12-16, the connector 162 includes a
cylindrical body 164 having a transverse bore 166 to receive one
end of the handle 160. The end of the handle is engaged by a
retaining screw or pin (not shown) received through an axial hole
15 168. Communicating with the hole 168 is an axial cavity 170
which receives the end of the switch shaft 43 protruding outside
the housing 6 (FIG. 7A). Set screws through threaded holes 172
secure the connector 162 to the shaft 43. Another transverse
threaded hole 174 receives a threaded shaft or pin 176 (FIG. 7A)
20 which defines a retainer means for engaging the retaining plate
128 on the cover 124, thereby retaining the cover 124 in its
closed position when the cover 124 is closed and the handle 160
is moved to the position wherein the switch 42 is in its
energizing position (the position of handle 160 shown in FIG.
25 7).

5 The coupling means of the drive means of the preferred embodiment includes a drive belt 178 extending around and connected to the cylindrical body 164 and the cylindrical pulley 150 as illustrated in FIGS. 2 and 7-9. A guard 179 (FIGS. 2 and 7) can be mounted over the belt 178.

10 The double interlock mechanism 138 further includes means for preventing the handle 160 from being moved in response to the cover 124 being moved from its closed position to its open position. As shown in FIGS. 2 and 7-9, this includes a block 180 pivotally connected to the side wall 90 above the connector 162. As more clearly shown in FIGS. 22-24, the block 180 has a hole 182 defined therein. The block 180 is manually movable to a handle enabling position atop the support shoulder 132 of the retaining plate 128 of the cover 124 when the cover is in its closed position as illustrated in FIGS. 2, 7 and 8. The block 180 automatically moves by gravity to a handle disabling position wherein the hole 182 of the block 180 receives the pin 176 in response to the handle 160 being in its switch de-energizing position and the cover being moved to its open position as is shown completed in FIG. 9. A hole 183 (FIGS. 22-24) defined in the block 180 receives a pivot pin 185 (FIGS. 7-9) connecting the block 180 to the side wall 90. A pin 184 (FIGS. 7-9) stops backward movement of the block 180.

25 In use, the motor control system of the present invention is transported to a location where it is to be connected to a power

source and a load, such as the power source 8 and the motor 10 and submersible pump 12 combination. Transportation to and placement at the location are facilitated by the single containment housing 6 which has all the electrical components located and interconnected therein.

Once at the location, conventional power connections are made to the high voltage terminals H1, H2, H3 within the compartment 86, and conventional load connections are made to the terminals A, B, C in the high voltage section 4a contained in chamber 84 of compartment 76. Access to the high voltage power input terminals H1, H2, H3 is through the door 88. Access to the normal operational switches 58, 60 and indicators 62, 64 of the motor controller section 4a is easy because these are mounted on the door 78 (FIG. 4). Access through the door 80 to the output terminals A, B, C and the other components within the high voltage section 4a, however, is limited depending upon the state of the double interlock mechanism 138.

Prior to operation, the handle 160 of the double interlock mechanism 138 would be in, or moved to, the position shown in FIG. 9. This allows the door 80 to be opened so that connections can be made to the output terminals A, B, C, and it also allows the cover 124 to be opened to permit access to the fuses 44 and the voltage adjusting switch handles 22, 24, 28. When the cover 124 is open, the block 180 drops into the position shown in FIG. 9 to prevent the handle 160 from being moved to the switch 42

energizing position.

Once the connections have been made and the output voltage selected, the door 80 and the cover 124 can be closed. To close the cover 124, the block 180 is manually lifted and placed on the retaining shoulder 132 as illustrated in FIG. 8. The handle 160 is now free to be pivoted clockwise into its switch 42 energizing position shown in FIG. 7. When the handle 160 is moved to this position, the pin 176 is concurrently pivoted clockwise and the latch 140 pivoted counterclockwise (as viewed in the drawings) to their respective positions shown in FIG. 7. The pin 176 then overlies the tongue portion 130 of the retaining plate 128 on the cover 124 and the latch 140 overlies the catch member 144 on the door 80 to retain the cover 124 and the door 80, respectively, in their closed positions. This prevents the cover 124 and the door 80 from being opened while the transformer circuit 2 and the motor controller circuits 4a, 4b are energized. Even when these circuits are energized, the low voltage section 4b is accessible through the door 78 if needed. If access is not needed, the door 78 can be closed and padlocked if desired. Operation of the motor controller circuit, itself, is conventional.

During operation of the transformer 14, the fuses 44 protect against damage resulting from an overload current in the secondary circuit. An overload current can occur in the secondary circuit, which causes an excessive input current to flow on the primary side, because of short-circuit faults in the secondary

winding, the motor or the intervening circuitry such as the cables. Such short-circuit faults reduce the secondary side impedance so that, with the output voltage substantially constant, the output current increases. Fuses 46 protect against a complete transformer failure. If one or more of the fuses 44 opens or clears when its current handling capacity is exceeded by the input current, it can be replaced when the transformer 14 is de-energized by the switch 42 and the cover 124 opened. The used fuses are extracted from and new ones inserted into the fuse carriers 48 in a known manner for the type of fuse used. The fuses 46 are not field replaceable without removing the top 106 or otherwise disassembling the enclosure to gain entry into the compartment 72. When the fuses 46 or 48 clear, the input voltage is removed from the primary winding so that the transformer and the other downstream components are de-energized.

During operation of the transformer 14, the electrostatic shields 34 and the tertiary windings 30, being placed between the primary and secondary windings, shield against electrostatically coupled transients. The tertiary windings 30 in combination with the capacitors 36, 38, 40 filter magnetically coupled transients.

During operation of the transformer 14, emergency shut-down can be effected by a person directly manually moving the handle 160 from its switch 42 energizing position (FIG. 7) to its switch 42 de-energizing position (FIG. 8). The handle 160 is directly

and safely accessible so that no hot stick or other tool is needed to actuate the handle.

From the foregoing description of the apparatus shown in FIGS. 1-27 and the operations thereof, it is apparent that the system can be used to provide the following described methods.

A method of controlling the energization of a motor circuit comprises selectably energizing and de-energizing the motor circuit from a primary winding circuit connected to a primary winding of a transformer. The motor circuit includes a three-phase electrical submersible pump motor and an electrically operated motor start-stop switch connected in a secondary winding circuit to a secondary winding of the transformer. The primary winding circuit includes a switch connected between the primary winding and a power source. The step of selectably energizing and de-energizing particularly includes manually operating the switch of the primary winding circuit without the aid of tools to selectably make and break a current conductive path between the primary winding and the power source. In response to making the current conductive path through unassisted manual operation of the switch in the primary winding circuit, a voltage exists in the secondary winding circuit for energizing the motor through the motor start-stop switch connected in the secondary winding circuit. In response to breaking the current conductive path through unassisted manual operation of the switch in the primary winding circuit, no voltage exists in the secondary winding cir-

cuit for energizing the motor through the motor start-stop switch connected in the secondary winding circuit.

For the following defined method, reference is again specifically made to a three-phase electrical submersible pump motor.

5 The motor is connected by electrical cables and an electrically operated contactor of a secondary winding circuit to a secondary winding of a transformer. The transformer also includes a primary winding connected by a primary winding circuit to a substantially constant a.c. voltage power source. A method of operating
10 this motor comprises applying the voltage of the power source across the primary winding of the transformer so that a substantially constant a.c. output voltage is induced across the secondary winding and an output current flows through the secondary winding, cables, contactor and motor in response to the contactor
15 in the secondary winding circuit being in a conductive state. The method also includes conducting input current through the primary winding circuit, including through a fuse thereof connected between the power source and the primary winding, the input current having a magnitude proportional to the output
20 current. The method further includes de-energizing the transformer and the secondary winding circuit in response to a short-circuit fault in the secondary winding or the secondary winding circuit. This is achieved by clearing the fuse in the primary winding circuit in response to the magnitude of the input current
25 reaching a predetermined level as a result of the magnitude of

the output current increasing to a level resulting from a short-circuit fault in the secondary winding or the secondary winding circuit.

5 A method of operating a three-phase motor connected by a secondary winding circuit to a secondary winding of a transformer, comprises energizing the motor and protecting the primary winding of the transformer from damage by an excessive input current resulting from an excessive output current caused to flow as a result of a fault in the secondary winding or the secondary winding circuit or the motor reducing the secondary side impedance to a short-circuit state and protecting any portion of the secondary winding and the secondary winding circuit which is upstream of the fault from the excessive output current. Energizing the motor includes applying a substantially constant
10 a.c. input voltage to the primary winding of the transformer so that a substantially constant a.c. output voltage is induced across the secondary winding. Energizing the motor also includes closing an electrically operated motor start-stop switch connected in the secondary winding circuit in between the secondary
15 winding and the motor so that the output voltage is applied to the motor and an output current flows through the secondary winding, the secondary winding circuit and the motor. The output current is responsive to the impedance of the secondary winding, the secondary winding circuit and the motor. Energizing the
20 motor further includes conducting an input current through the
25

primary winding, which input current has a magnitude responsive to the output current. Protecting the circuits upstream of the fault includes automatically clearing a fuse connected to the primary winding. This clearing occurs in response to the input current exceeding a predetermined magnitude. Upon clearing, the input voltage is removed from the primary winding.

Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned above as well as those inherent therein. While a preferred embodiment of the invention has been described for the purpose of this disclosure, changes in the construction and arrangement of parts can be made by those skilled in the art, which changes are defined by the appended claims.

What is claimed is:



CLAIMS

1. A system for operating a three-phase motor, comprising:

5 a transformer including a three-phase primary winding and a three-phase secondary winding, said transformer providing transformation of a three-phase input voltage to a three-phase motor energizing voltage;

secondary winding circuit means for connecting a three-phase motor to said secondary winding, said secondary
10 winding circuit means including motor control means, connected to said secondary winding to receive said three-phase motor energizing voltage from said transformer, for controlling the application of said three-phase motor energizing voltage from said secondary winding to a
15 connected three-phase motor; and

primary winding circuit means for connecting to a three-phase power source and for controlling whether current flows through said three-phase primary winding from a connected three-phase power source, said primary winding
20 circuit means including master on/off switch means, connected to and located in a common housing with said primary winding of said transformer and responsive to direct manual operation with means for manual operation located within reach of a person adjacent said motor
25 control means, for selectably energizing or de-energizing said transformer so that said three-phase motor energizing voltage is thereby selectably provided or not provided to said motor control means.



2. A system as defined in claim 1, wherein said switch means is adapted for de-energizing said transformer even when current is flowing through said secondary winding and a three-phase motor connected thereto.

5 3. A system as defined in claim 1 or 2, wherein:
said three-phase primary winding is adapted for receiving an input voltage from said three-phase power source, said input voltage being within the range of about 4160 Vac to about 34500 Vac; and

10 said three-phase secondary winding is adapted to respond to said input voltage received by said three-phase primary winding so that said three-phase secondary winding provides said three-phase motor energizing voltage as a three-phase voltage within the range of about 460 Vac to
15 about 4160 Vac.

4. A system as defined in claim 1, 2 or 3, wherein said transformer is adapted for conducting all the electric power to be consumed by said motor operating system and a connected three-phase motor.

20 5. A system according to any one of the preceding claims, wherein said transformer is a three-phase transformer providing the only voltage level conversion between said power source and said motor control means.

6. A system according to any one of the preceding
25 claims, wherein said transformer further includes tertiary winding means for providing a three-phase motor control circuit energizing voltage to a motor controller of said



motor control means and for shielding said secondary winding from transients.

7. A system as defined in claim 6, wherein said tertiary winding means is disposed between said primary and secondary windings.

8. A system as defined in claim 6 or 7, wherein said transformer further includes capacitance means connected to said tertiary winding means for filtering transients.

9. A system according to any one of the preceding claims, wherein said primary winding circuit means further includes fuse means, connected in electrical series with said switch means, for stopping current flow within said primary winding circuit means in response to current in said primary winding circuit means exceeding a predetermined level in response to a short-circuit fault in said secondary winding or said secondary winding circuit or a three-phase motor connected thereto.

10. A system according to any one of claims 1 to 8, further comprising fuse means, connected in electrical series with said switch means, for stopping current flow in said primary winding in response to a current through said fuse means exceeding a predetermined level in response to a short-circuit fault on the secondary side of said transformer.

11. A system according to any one of claims 1 to 8, further comprising three fuses, each of said fuses



connected in electrical series with said switch means for a respective phase of said three-phase power source.

12. A system according to any one of claims 1 to 8, further comprising:

5 a first set of three fuses, each of said fuses of said first set connected in electrical series with said switch means for a respective phase of said three-phase power source and each of said fuses of said first set providing means for interrupting fault current when the
10 fault current has a magnitude limited solely by the internal impedance of said three-phase power source; and
a second set of three fuses, each of said fuses of said second set connected in electrical series with said switch means and the respective fuse of said first set for
15 a respective phase and each of said fuses of said second set providing means for interrupting fault current when the fault current has a magnitude limited solely by the sum of the internal impedance of said three-phase power source and the impedance of said transformer with said three-phase
20 secondary winding short-circuited.

13. A system according to any one of claims 1 to 8, further comprising a current-limiting fuse and a load-sensing fuse connected in electrical series with said primary winding and said switch means.

25 14. A system according to any one of the preceding claims, further comprising a single transportable containment means for holding said transformer, said



primary winding circuit means and said secondary winding circuit means.

15. A system according to claim 14 and any one of claims 8 to 13, wherein said transformer, said switch means and said fuses are submerged in oil within said containment means.

16. A system as defined in claim 13, 14 or 15, wherein said containment means includes:

an internal door and an external cover, both said door and said cover movable between respective open and closed positions; and

double interlock means, connected to said switch means, for retaining said door and said cover in said respective closed positions in response to said switch means being operated to an energizing position.

17. A system according to any one of claims 13 to 16, wherein said containment means includes a first compartment and a second compartment, said first compartment having said transformer and said primary winding circuit means disposed therein within a volume of liquid contained in said first compartment, and said second compartment having said motor control means disposed therein.

18. A system as defined in claim 17, wherein:
said motor control means includes a high voltage section and a low voltage section; and

said second compartment includes a first chamber and



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a second chamber, said first chamber having said high voltage section of said motor control means disposed therein and said second chamber having said low voltage section of said motor control means disposed therein.

5 19. A system as defined in claim 18, wherein:
 said containment means further includes a door disposed between said first and second chambers of said second compartment;

 said system further comprises a latch disposed in
10 said first chamber so that said latch is movable between a first position, wherein said latch is positioned to engage said door, and a second position, wherein said latch is positioned to disengage said door; and

 said means for manual operation includes manual
15 operating means disposed on the exterior of said containment means for concurrently operating said switch means and said latch so that said latch is in a first position in response to said switch means being operated by said manual operating means to energize said three-phase
20 primary winding and so that said latch is in said second position in response to said switch means being operated by said manual operating means to de-energize said three-phase primary winding.

 20. A system as defined in claim 19, wherein:

25 said system further includes output selection switch means, connected to said three-phase secondary winding and having at least a part thereof mounted on the exterior of