United States Patent [19]

Caldwell et al.

[11] **3,769,521**

[45] **Oct. 30, 1973**

[54] **IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM**

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[22] Filed: **Oct. 5, 1972**

[21] Appl. No.: **295,403**

[52] **U.S. Cl.** **307/95,** 61/54, 166/0.5, 175/5, 204/196

[51] **Int. Cl.** **B01d 13/02**

[58] **Field of Search** ..... 166/244 C, .5; 307/95; 204/196; 175/6, 5; 61/54

[56] **References Cited**

UNITED STATES PATENTS

2,998,371	8/1961	Sabins	204/196
3,616,418	10/1971	Anderson et al.	204/196
3,692,650	9/1972	Kipps et al.	204/196 X

Primary Examiner—James D. Trammell
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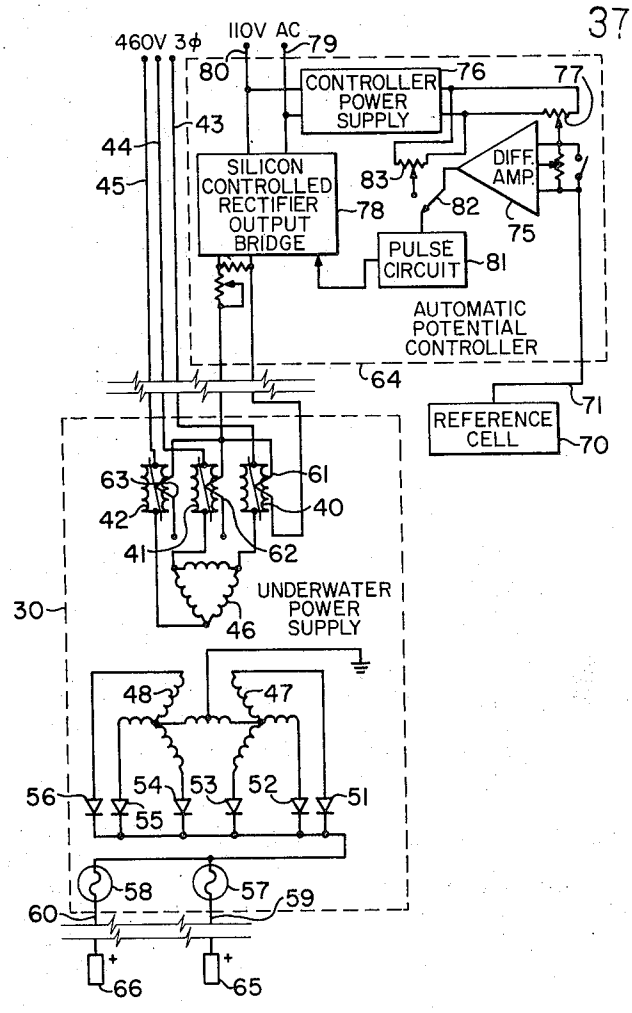
[57] **ABSTRACT**

An impressed current cathodic protection system for a marine structure includes an elongated supporting member which can be lowered into position adjacent the underwater structure to be protected, an underwater power supply mounted in the supporting member for converting high voltage alternating current from a source above the water's surface to low voltage direct current, one or more anodes mounted on the supporting member near the power supply, a potential controller for regulating the level of protection provided, and a reference cell for monitoring the system.

20 Claims, 8 Drawing Figures



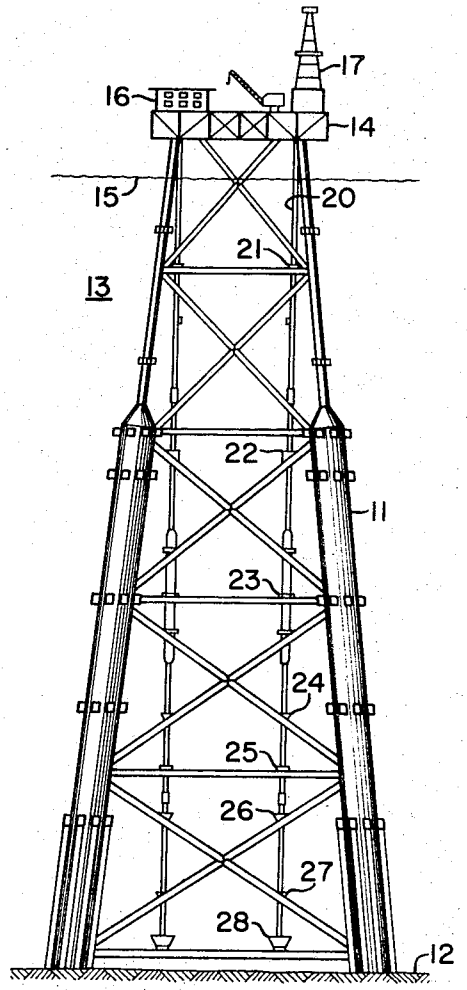


FIG. 1

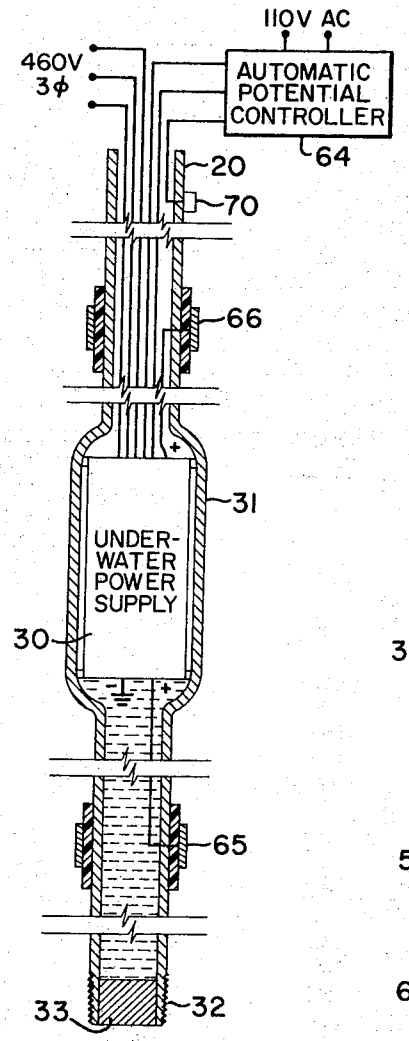


FIG. 2

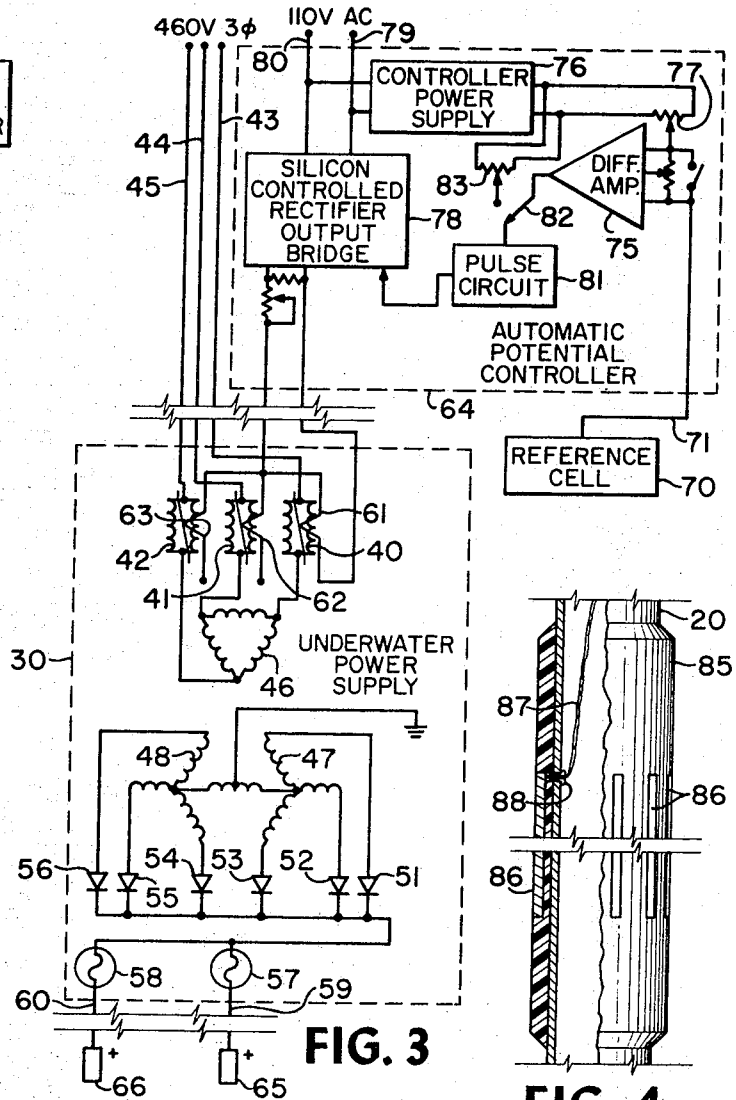


FIG. 3

FIG. 4

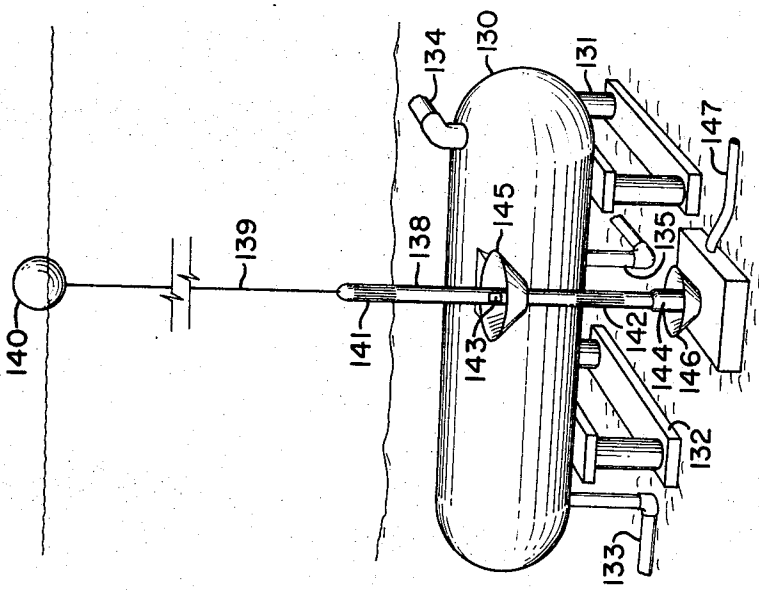


FIG. 8

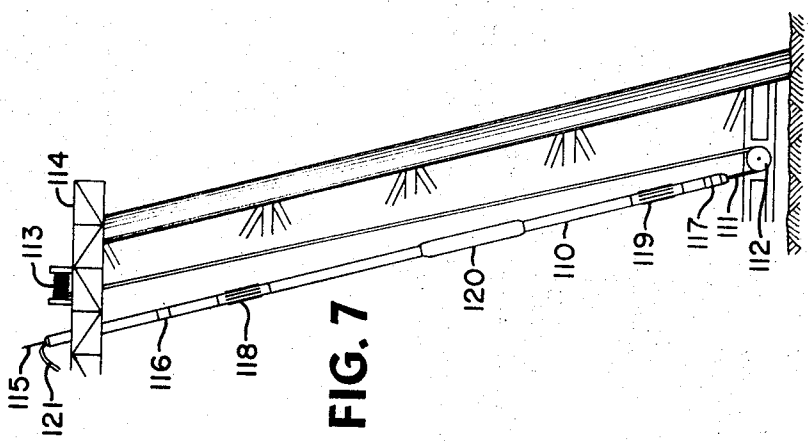


FIG. 7

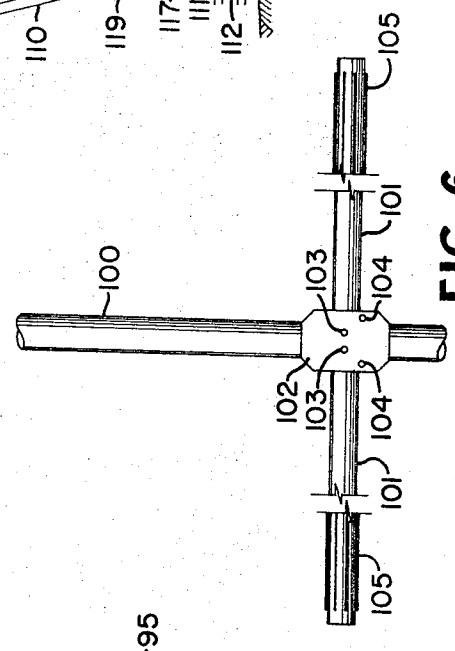


FIG. 6

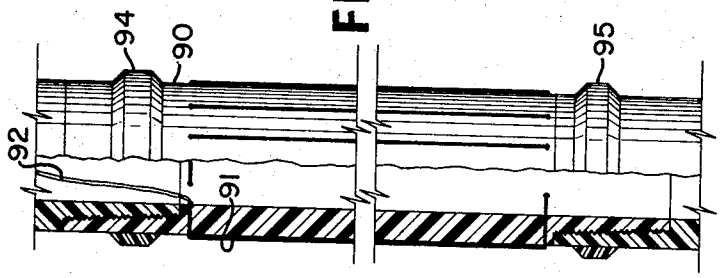


FIG. 5

IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the cathodic protection of marine structures and is particularly concerned with an improved impressed current system for the protection of offshore platforms and similar structures.

2. Description of the Prior Art

Offshore platforms used in the petroleum industry and similar marine structures are usually provided with cathodic protection systems for combatting underwater corrosion. For shallow water installations, galvanic systems using sacrificial anodes of magnesium, zinc or aluminum are often employed. Systems of this type require no electrical power and generally present few maintenance problems. Their principal disadvantage is that they are heavy, expensive and of relatively short life. A typical installation on a platform in 200 feet of water, for example, will require about 30 tons of aluminum of 90 tons of zinc to provide protection over a 10-year period and may cost on the order of from 2 to 3 cents per year per square foot of exposed platform area. On larger structures designed for installation in deeper waters, these costs quickly become prohibitive.

Because of the expense associated with galvanic systems, offshore platforms designed for installation in water depths greater than about 150 feet are usually provided with impressed current cathodic protection systems. These systems, which normally make use of lead-silver anodes of lead-platinum bielectrodes supplied with low voltage direct current from surface-mounted transformers and rectifiers, generally weigh about one-fifth as much as galvanic aluminum systems and provide adequate protection for about 1 and ½ cents per year per square foot of submerged platform area. Studies indicate, however, that conventional impressed current systems may not be satisfactory for many of the large structures now being designed for use in deep water. Experience has shown that the lead type anodes can withstand only limited current densities and may not be adequate for such structures. Moreover, the transmission of low voltage, high amperage current to such anodes from the surface results in high heating losses and requires the use of heavy conductors which add significantly to the loading of the structure. Other difficulties include the susceptibility of such systems to damage due to their exposed locations, reliability problems associated with the anodes and shielding systems, and safety problems encountered with the on-deck equipment. Such systems therefore leave much to be desired.

SUMMARY OF THE INVENTION

This invention provides an improved impressed current cathodic protection system which alleviates many of the problems associated with systems available in the past and facilitates the use of cathodic protectiaon for off-shore platforms and other marine structures. The improved system of the invention includes an elongated supporting member which can be lowered into position adjacent the structural members to be protected and later retrieved as necessary, an underwater power supply mounted on the supporting member for converting high voltage alternating current from a surface-mounted source to low voltage direct current, one or more low deterioration rate anodes mounted on the supporting member near the structural members which are to be protected, a potential controller for regulating the level of protection provided, and a reference cell for monitoring the system.

The supporting member employed in the improved system will preferably comprise an elongated string of pipe or conduit which can be lowered into position from the water's surface through guides on the structural members and connected to the structure near the lower end of the member. The pipe or conduit may be metallic, in which case it will serve as the negative conductor between the power supply and the structure, or may be made of nonconducting material and provided with an internal conductor to ground. If a metallic pipe or conduit is used, the anodes employed will normally be mounted on dielectric shields carried on the outer surface of the pipe. These shields may be dispensed with if a conduit of nonconducting material is employed. Arms may be attached to the pipe of conduit for supporting the anodes if desired. In lieu of such a pipe or conduit, the protection system may be mounted on an insulated cable which can be pulled downwardly into position on the structure and returned to the surface when necessary.

The underwater power supply employed in the system of the invention will normally comprise a transformer and rectifier for converting high voltage alternating current to low voltage direct current. An automatic potential controller including a magnetic amplifier, silicon controlled rectifiers, and the like may also be included or instead may be installed above the water's surface. The power supply will normally be enclosed in a suitable housing incorporated in the retrievable pipe string, conduit or cable system at a point near the anodes. Two or more power supply units may be provided in each retrievable system if desired. High voltage alternating current leads, preferably 60 cycle three phase, extend from a power source on the platform or other structure through the supporting member to the power supply unit. These may be encased in an inner conduit which extends downwardly within the outer conduit and is provided with a plug-in connection at the transformer. Provisions may be made for pulsing either the high voltage alternating current or the low voltage output from the rectifier. Reference cell monitors used to establish the required potential and regulate the controller are provided on the supporting member and may also be located on the marine structure itself. Manual controls and instrumentation are located on the deck of the structure or at an equally accessible surface location.

The anodes employed in the retrievable system will preferably be low deterioration rate anodes such as platinum over tantalum, platinum over niobium, platinum over titanium, platinum studded lead, or the like. As indicated earlier, these are mounted on the supporting member or on arms extending therefrom and are connected to the potential controller through leads extending within the supporting member.

The system of the invention has numerous advantages over impressed current cathodic protection systems available in the past. The use of an elongated pipe or similar supporting member and an underwater power supply as described above permits the transmission of low voltage, high amperage direct current to the anodes with negligible power losses and without the

heavy conductors required in earlier systems; provides significantly better cooling of the transformer, rectifier, and automatic potential controller and thus makes possible the use of lighter, more compact units; makes it possible to vary the level of the anodes with respect to the submerged structure; results in savings in deck space and reduces platform structural requirements; provides greater safety because the power supply and most of the associated leads are underwater where danger of fire or damage due to lightning is minimized; eliminates or greatly reduces radio frequency interference; provides greater reliability because of the shorter direct current power leads; permits the use of long life dielectric shields mounted directly on the supporting member; makes possible periodic maintenance and repair without the use of divers; and provides a system which is fully compatible with existing off-shore equipment and petroleum industry practices. As a result of these and other advantages, the system of the invention permits substantial economic savings over other cathodic protection systems which have been employed heretofore, particularly in deep water installations.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 in the drawing is a schematic representation of an offshore platform provided with the improved impressed current cathodic protection system of the invention;

FIG. 2 is an enlarged longitudinal cross-section illustrating the system of FIG. 1 in greater detail;

FIG. 3 is a schematic electrical diagram illustrating the system of the invention;

FIG. 4 is a fragmentary longitudinal cross-section through the supporting member in an embodiment of the invention using a metallic supporting member;

FIG. 5 is a fragmentary longitudinal cross-section through the non-metallic supporting member of an alternate embodiment of the invention;

FIG. 6 illustrates the use of arms attached to the supporting member for positioning the anodes employed in accordance with the invention;

FIG. 7 is a fragmentary view of another embodiment of the invention in which the apparatus is supported by means of a cable or similar member; and,

FIG. 8 illustrates still another embodiment for the protection of an underwater separator or similar device.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 in the drawing is a schematic representation of an offshore platform provided with the improved impressed current cathodic protection system of the invention. The platform depicted in FIG. 1 includes an open framework 11 of tubular steel members extending from the bottom 12 of a body of water 13 to a platform 14 located a distance of 50 feet or more above the surface of the water 15. The upper deck of the platform is provided with a shelter 16 for the housing of personnel and equipment, with a derrick 17 for use in well operations, and with other conventional items of equipment. The layout of the deck and the equipment provided thereon will depend in large part upon the particular purpose for which the platform is intended. In the case of an offshore platform to be used for the production of crude oil and natural gas, for example, the facilities provided will normally include risers extending upwardly along the platform structure to production facilities located on the deck, equipment for use in well maintenance and workover operations, offloading facilities, and the like. It will be understood that the invention is not restricted to the particular type of platform shown and may be employed with a variety of different structures, including offshore drilling and production platforms of the monopod type, buoyant tower structures which are hinged near the bottom to permit limited lateral movement in response to waves and currents, seadrome type structures held in place by three or more parallel members hinged near the ocean floor, offshore storage facilities, marine radar stations, semisubmersible drilling barges, underwater pumping and separator stations, and the like. Although the details of the cathodic protection system employed may vary somewhat depending upon the particular type structure to be protected and the purpose for which it is intended, the principal features of the system will be substantially the same regardless of the offshore structure to which it is applied.

The cathodic protection system employed on the offshore structure of FIG. 1 includes an elongated supporting member 20 which is secured near its upper end to platform 14 and extends downwardly through guides 21, 22, 23, 24, 25, 26 and 27 on the platform framework to a receptacle located within a guide funnel 28 near the base of the platform. The supporting member 20 will normally comprise a string of steel pipe or tubing between about 2 and about 9 inches in diameter but in some cases may be made of hard plastic or other dielectric material. It is generally preferred that the string of pipe or conduit be made up of threaded sections about 30 feet in length to facilitate its disassembly when withdrawal of the system to the surface becomes necessary, although welded or bolted connections can be used in lieu of threaded joints if desired. The guide members 21 through 27 through which the pipe string extends are funnel-shaped members mounted at appropriate points on horizontal members of the platform and are of sufficient diameter to pass enlarged sections of the string. The lower end of member 20 normally contains a plug or other fluid-tight closure to prevent the entry of water and the escape of oil or other fluid from within the member and will be provided with threads, detents or other means for holding the lower end in place within the receptacle in guide funnel 28. If member 20 is made of a dielectric material, an electrical connection to ground may be provided by extending a ground conductor through the closure so that it makes contact with the structure within the receptacle. The location of supporting member 20 and the associated guide members will depend in part upon the configuration of platform framework 11 and the electrical characteristics of the cathodic protection system. The anodes employed in the system are normally capable of providing effective protection over relatively large areas. On large structures, however, a plurality of supporting members spaced at selected intervals may be used to insure adequate protection for the entire structure. The system depicted in FIG. 1 includes a second supporting member which is essentially identical to supporting member 20 and will therefore not be described in detail.

Supporting member 20 in the apparatus of FIG. 1 serves as a conduit through which the electrical leads of the cathodic protection system extend between the

deck of the platform and the underwater components. These components may include an underwater power supply containing a transformer and rectifier for converting high voltage alternating current produced by a generator on the platform deck into low voltage direct current, an automatic potential controller for regulating the amount of current delivered by the system, one or more anodes upon which the delivered current is impressed, and one or more reference cells for monitoring and controlling the automatic potential controller. As indicated more clearly in FIG. 2 of the drawing, the power supply 30 will normally be enclosed in a cylindrical housing 31 which is connected into the supporting pipe string 20 at an intermediate point along its length. The automatic potential controller may be located in the same housing or, if desired, may be positioned at the surface or placed in a separate housing positioned a short distance away from housing 31. As pointed out earlier, it is preferred that the entire pipe string assembly be made up of threaded pipe secitons which have sufficient mechanical strength to resist wind, wave, and current forces and to withstand impact by ice and flotsam in both the tidal splash zone above the water's surface and the submerged zone beneath the surface. Longitudinal ribs may be provided to increase the strength of the string if necessary. This use of a supporting member made up of sections which can be disconnected from one another permits rapid retrieval of the member without the use of divers and results in a system which is compatible with equipment and procedures currently in use in the petroleum industry. The lowering of the supporting member into position, the locking of the member in place by threading the lower end 32 containing closure 33 into the receptacle in funnel 25, the unlocking of the pipe string, and its retrieval can all be accomplished with conventional hoisting equipment and tools normally available on offshore platforms for use in oil field drilling and production operations. The use of such a pipe string also provides an effective negative return from the platform structure by draining current at the threaded connection at the bottom of the string and at the top where the pipe string is supported on the platform deck.

The underwater power supply employed for purposes of the invention, designated by reference numeral 30 in FIG. 2 of the drawing, is shown in greater detail in FIG. 3. The power supply depicted is a saturable reactor type system which includes saturable reactors 40, 41 and 42 connected in series with the three input lines 43, 44, and 45 from a 440 to 460 volt, 60 cycle three-phase alternator located on the platform, a step-down transformer having a delta-connected primary 46 which is connected to the three saturable reactors and two low voltage secondary windings 47 and 48, a three-phase double-wye silicon rectifier assembly comprising rectifiers 51, 52, 53, 54, 55 and 56 connected to the secondary windings of the transformer, and leads extending from the rectifier assembly through suitable fuses, circuit breakers, or other protective devices 57 and 58 to the anode leads 59 and 60. The step-down transformer reduces the high voltage alternating current to a voltage level between about 3 and about 50 volts and the rectifiers in turn convert this to low voltage direct current. The control windings 61, 62 and 63 of the saturable reactors, energized by the atuomatic potential controller 64 as will be pointed out in greater detail hereafter, serve to regulate the input to the primary winding of the step-down transformer and thus regulate the amount of current which is delivered through the rectifiers to the anodes 65 and 66 of the cathodic protection system. Saturable reactor type power supplies useful for purposes of the invention are available from a variety of different commerical sources and will therefore be familiar to those skilled in the art. It should be understood that the use of a saturable reactor type power supply is normally preferred but that other systems may also be employed. These include silicon-controlled rectifiers, servo-controlled variable transformers, servo-operated variable reactance devices, thyristers and the like. Other voltage levels and frequencies may also be employed.

The location of the saturable reactor type or other power supply described above in housing 30 on supporting member 20 permits substantial reductions in the size and weight of the power supply because of the better cooling obtained. Heat transfer through the housing wall to the surrounding sea water will normally be significantly better than could be obtained with a unit mounted on the platform deck. A light hydrocarbon oil, a silicone fluid, a transformer oil, or the like will normally be maintained within supporting member 20 and the housing surrounding the power supply in order to further improve heat transfer and maintain high operating efficiencies. The smaller size and lower weight of the power supply unit reduces the platform structural requirements from a loading and lateral wave force standpoint. More importantly, the use of a submerged power supply eliminates the necessity for devoting a substantial portion of the platform deck to housing the power supply. In conventional cathodic protection systems, approximately 0.1 square foot of space is required per ampere of power available at the anodes. A platform located in 1,000 feet of water with a total current demand of 30,000 amperes would therefore require approximately 3,000 square feet of deck space to accommodate the power supply equipment. This saving in space by virtue of the system of the invention results in significant economic savings.

The automatic potential controller 64 in the apparatus of FIGS. 1 through 3 monitors the level of protection of the submerged portion of the platform by means of one or more reference cells 70 and provides a signal to the saturable reactor control windings for adjusting the amount of current fed to anodes 65 and 66 so that the desired level can be maintained. the reference cells employed will normally contain silver-silver chloride, zinc, or other suitable electrodes of conventional design. Each such cell is mounted on the exposed structure, preferably at a point where the degree of protection afforded by the cathodic protection system can be expected to be low and preferably a substantial distance from the nearest anode. The silver-silver chloride electrode normally consists of a silver screen coated with silver chloride and welded about a silver rod. This electrode is mounted in a shock-resistant plastic tube or similar housing and connected through a water-tight seal to an insulated copper cable which is protected against contact with the water. The difference in potential between the electrode and the structural member of the platform 11 adjacent to which it is mounted causes a small current to flow. This current is conducted through the copper conductor to a high impedance volt meter on the deck of the platform, not shown in the drawing, which is used for monitoring purposes.

This current is also conducted through a second conductor 71 in supporting member 20 to the automatic potential controller 64. The controller can either be located at the surface as shown in FIGS. 2 and 3 or mounted in underwater housing 31. The system of the invention is not restricted to the use of a silver-silver chloride electrode and may employ other commercially available reference electrodes which will produce potential differences which can be used to monitor operation of the system.

The automatic potential controller 64 preferably includes a high gain differential direct current amplifier 75 which operates on two input signals, the potential difference between the reference electrode 70 and the platform structure 11 and a control voltage from controller power supply 76 and potentiometer 77 representing the desired potential difference between the electrode and the structure. The difference between these two input voltages is amplified by the controller and used to regulate the output voltage fed to the control windings 61, 62 and 63 of the saturable reactor power supply 31. This regulation is accomplished by means of a silicon controlled rectifier output bridge 78 which acts as a switch to pass a portion of an alternating current powerline voltage from input leads 79 and 80 to the control windings. The rectifiers in the bridge circuit are turned on for a very short period of time during each cycle of the alternating current in response to pulses from a pulse control circuit 81. When the output from the differential amplifier 75 is zero, the pulse control circuit pulses the silicon controlled rectifiers at the end of each cycle of the alternating current so that no output voltage is conducted to the saturable reactor control windings 61, 62 and 63. As the output from the differential amplifier increases, the timing of the pulses is advanced toward the beginning of each cycle of the alternating current so that more power flows through the silicon controlled rectifiers to the control windings of the saturable reactor power supply. The rectifiers turn themsevles off automatically at the end of each cycle of the alternating current. The output voltage fed to the saturable reactor windings will thus range between zero and about 100 volts direct current, depending upon the potential difference between the electrode in reference cell 70 and the structure 11 and the desired potential difference. The controller will normally also include a provision for manual control by shutting off the differential amplifier output by means of switch 82 and substituting an adjustable voltage from potentiometer 83, which can be controlled from the surface. The differential amplifier may be provided with automatic gain control to permit changes in the sensitivity of the controller to differences between the two inputs to the differential amplifier. Although the use of a controller of this type is normally preferred because it uses commercially available solid state components and can therefore be made compact and will require little or no maintenance, it will be understood that other types of controllers can also be used. A variety of different control systems suitable for impressed current cathodic protection systems are available commercially and can be readily adapted for purposes of the invention by one skilled in the art. Although the controller shown is located at the surface, it is often advantageous, as pointed out above, to position both the controller and power supply beneath the water to further reduce the danger of fire due to electrical malfunctioning of the equipment or lighting, shorten the required length of direct current power leads and thus give greater reliability, lower power losses and improve safety, and eliminate or reduce radio frequency interference, particularly where high frequency power or pulsed DC power is used.

The anodes employed for purposes of the invention will preferably be low deterioration anodes of the platinum over titanium, platinum over niobium, or platinum over tantalum type. These anode materials last for long periods and normally permit the use of relatively small anodes at high current densities. They are therefore particulary useful in the retrievable cathodic protection system disclosed herein. Other types of anodes may also be employed, however. Although other configurations can also be used, anodes mounted directly on the supporting member 20 are normally preferred. FIG. 4 in the drawing illustrates one embodiment of the invention utilizing such an anode. Supporting pipe 20 in this particular embodiment is a string of 2½ inch diameter steel pipe extending downwardly into the water between the structural members of the platform. Bonded to the outer surface of the pipe string at the anode level is a dielectric shield 85 which serves to isolate the anode from the supporting member and promote uniform distribution of the protective current about the anode. This dielectric shield may be made of coal tar epoxy resin, phenolic epoxy resin, fiberglass reinforced polyester resin, polyurethane, polyvinylchloride, neoprene rubber, or the like. The material selected may be applied to the pipe section by conventional techniques involving the use of baking, flame sprays, fluidized beds, or the like. Alternatively, a precast section of polyvinylchloride pipe or similar material can be inserted over the supporting member and held in place mechanically. Polyvinylchloride pipe may be used in conjunction with a primer of coal tar epoxy resin or a similar dielectric material. The metallic anode 86 preferably comprises a plurality of longitudinal tantalum strips, or rods, each covered with a thin layer of platinum on the order of from about 0.00005 to about 0.005 inch in thickness. These strips are interconnected and will normally be mounted so that the outer surfaces of the platinum coated metal are slightly recessed with respect to the surface of the dielectric material at each end of the anode and are thus protected against damage as the supporting member is raised and lowered. Conductor 87 extends through an opening in the wall of supporting member 20 and dielectric sleeve 85 to the back side of the tantalum base metal of one or more of the strips. A rubber or plastic plug 88 surrounds the end of the insulated conductor to prevent contact with the wall of the supporting member and preclude the leakage of oil or other fluid from within the supporting member. If desired, the anodes may be mounted at or near joints in the supporting member to facilitate assembly of the apparatus.

FIG. 5 in the drawing illustrates an alternate embodiment of the apparatus in which a dielectric supporting member 90 of polyvinyl chloride, glass reinforced polyester, or similar material is employed in place of the metallic supporting member referred to earlier. This use of a dielectric supporting member eliminates the necessity for a dielectric shield. Anode 91 comprises a platinum coated rod or wire of titanium or the like which extends through openings in the supporting member to form a plurality of anode surfaces extending

parallel to the longitudinal axis of the supporting member. The openings in the supporting member through which the anode passes are sealed to prevent fluid leakage. Conductor 92 is connected to one end of the anode and extends to the underwater power supply. Rings 94 and 95 on the outer surface of the supporting member near the ends of the anode extend outwardly beyond the anode surfaces to protect them against damage. In lieu of using these rings, the anode can be recessed in shallow slots or grooves extending parallel to the longitudinal axis of the supporting member in the outer surface thereof.

The dimensions and configuration of the anodes will depend in part upon the area to be protected by each anode, the current densities to be used, and other factors. In general, however, it is normally preferred that the anodes be from about 2 to about 10 feet in length and that, if a metallic supporting member is used, the dielectric sleeve extend about 10 feet or more above and below the ends of the anode. This isolates the anode from the supporting member and helps insure substantially uniform protection over a relatively large area surrounding the anode.

In lieu of mounting the anodes on the supporting member as described above, extensible arms on which the anodes are located may be used. FIG. 6 in the drawing illustrates schematically an arrangement in which a metallic supporting member 100 extends downwardly in the water below the deck of the platform and arms 101 of polyvinylchloride or a similar dielectric material are hinged to the supporting member by means of brackets 102 and hinge pins 103. Each arms swings upwardly about the hinge pin as the assembly is lowered through the guide members on the platform and is held in the extended position after it is passed through the guide members by a shear pin 104. The metallic anode 105 is mounted on the outer end of the arm 10 feet or more from the supporting member. When it becomes necessary to retrieve the apparatus, the assembly can be pulled upwardly through the guide members with sufficient force to cause the shear pins to fail and permit the arms to move downwardly into positions parallel to the supporting member. The shear pins can be easily replaced before the assembly is to be lowered back into position.

FIG. 7 in the drawing depicts still another embodiment in which the lower end of the supporting member 110 is connected to a cable 111 which extends about a sheave 112 or similar member near the base of the platform and passes upwardly to a winch or reel 113 on the platform deck 114. The upper end of the supporting member 110 is connected to a cable 115 by means of which it is held in tension. The supporting member may be of either metallic or dielectric material and is provided with reference cells 116 and 117 and anodes 118 and 119 on its outer surface. The electronic components of the apparatus are housed in capsule 120 at an intermediate point on the supporting member. Power is supplied from the surface through cable 121. Guide members on the platform structure which help stabilize the assembly and prevent lateral movement are not shown in the drawing. This type of installation facilitates adjustment of the vertical position of the anodes and permits rapid withdrawal of the equipment to the surface if necessary.

The use of the system of the invention for the cathodic protection of an underwater oil-gas separator or similar totally submerged installation is illustrated in FIG. 8 of the drawing. The installation shown includes a separator vessel 130 which is mounted on supports 131 and 132 and provided with an input line 133 and output lines 134 and 135. Valves, remote control apparatus and other features which will normally be provided but have nothing to do with the cathodic protection system have been omitted in order to simplify the drawing. The protection system employed includes an elongated, generally cylindrical supporting member 138 from which a line or cable 139 extends upwardly to a float or buoy 140 at the water's surface. This buoy serves to mark the location of the apparatus and facilitate retrieval of the supporting member but is not essential. In lieu thereof, the upper end of the member may be fitted with a spearhead or other device which can be engaged by a retrieving tool lowered from the surface when retrieval becomes necessary. The supporting member is provided with anodes 141 and 142, reference cell 143, and an underwater power supply and automatic potential controller housed in an enlarged lower section 144. All of these components may be similar to those described earlier in connection with other embodiments of the invention.

An upper guide funnel 145 is mounted on the side of separator vessel 130 for guiding the supporting member into the desired position adjacent the vessel. The lower end of enlarged section 144 seats in a receptacle located within lower guide member 146 to provide electrical connections between the supporting member and multiconductor electrical cable 147. Although a variety of different electrical connecting devices designed for underwater service can be used, it is normally preferred that the connecting device be an inductance type connector containing windings similar to those in a transformer. This premits the transmission of alternating current or pulsed direct current from the cable into the supporting member without direct electrical connections. Such connectors have been described in the literature and will therefore be familiar to those skilled in the art. Cable 147 extends to an offshore platform or shore station equipped with alternators or the like for providing the required electrical energy to the system. The alternating current used to energize the automatic potential controller and underwater power supply in supporting member 138 can be transmitted through the cable over long distances without significant power losses.

Because it makes use of dependable solid state components, requires the transmission of direct current voltages over only short distances, and operates at low temperatures, the system of FIG. 8 will normally present few operating or maintenance problems. In the event that the replacement of a component or other maintenance or repair work becomes necessary, however, the supporting member containing all of the electrical components except the cable 147 and the receptacle through which power is transmitted to the system can be readily retrieved to permit such work at the surface. Underwater television, sonic locating devices, and similar apparatus can be employed to facilitate retrieval and reinstallation of the apparatus. Divers are not ordinarily required for either retrieval or reinstallation and hence any repairs or maintenance that do become necessary can be carried out relatively inexpensively. It will be understood that the system of FIG. 8 is not restricted to the use of a single supporting mem-

ber as shown and that underwater storage facilities, pumping stations, and other large underwater installations may make use of a plurality of such members spaced at intervals selected to insure cathodic protection of the entire installation. In the event that such an installation is provided with a man-rated chamber in which divers or personnel transferred from an underwater vehicle may perform certain maintenance and repair operations, the automatic potential controller may be located in the chamber rather than in the supporting member as shown. These and other modifications of the system depicted in FIG. 8 will be apparent to those skilled in the art.

We claim:

1. An impressed current cathodic protection system for a marine structure which comprises a supporting member that can be lowered in the water into position adjacent said structure and later retrieved, an underwater power supply on said supporting member for converting an applied alternating current to low voltage direct current, at least one anode on said supporting member, means for transmitting direct current from said underwater power supply to said anode, and means for transmitting alternating current from a remote source to said underwater power supply.

2. Apparatus as defined by claim 1 incluidng a potential controller for regulating the direct current voltage applied to said anode, at least one reference cell for monitoring the potential difference between said anode and said structure, and means for transmitting a signal from said reference cell to said potential controller.

3. Apparatus as defined by claim 2 wherein said potential controller is mounted within said supporting member.

4. Apparatus as defined by claim 2 wherein said potential controller comprises a differential amplifier and a silicon controlled rectifier output bridge.

5. Apparatus as defined by claim 1 wherein said supporting member is made of a dielectric material.

6. Apparatus as defined by claim 1 wherein said supporting member comprises an elongated metallic conduit and a dielectric shield is positioned between said conduit and said anode.

7. Apparatus as defined by claim 1 wherein said supporting member includes an extensible arm and said anode is mounted on said arm.

8. Apparatus as defined by claim 1 wherein said underwater power supply comprises a saturable reactor.

9. Apparatus as defined by claim 1 wherein said anode includes a surface coating of platinum.

10. Apparatus as defined by claim 1 wherein said means for transmitting alternating current to said underwater power supply comprises a submerged electrical cable extending to an electrical connector located near the lower end of said supporting member.

11. Apparatus as defined by claim 1 wherein said means for transmitting alternating current to said underwater power supply comprises an electrical cable which extends downwardly in said supporting member from a power source located on said marine structure above the water's surface.

12. An impressed current cathodic protection system for a marine structure having a platform located above the water's surface and metallic structural members extending downwardly below the surface which comprises an elongated tubular supporting member of sufficient length to extend downwardly from said platform to a point adjacent said structural members, an underwater power supply mounted in said supporting member at an intermediate point therein for converting alternating current to low voltage direct current, means for transmitting alternating current from a power source on said platform to said underwater power supply, at least one anode mounted on said supporting member, means in said supporting member for transmitting direct current from said underwater power supply to said anode, an automatic potential controller for regulating the direct current voltage applied to said anode, a reference cell for monitoring the potential difference between said anode and said structural members, and means for transmitting a signal from said reference cell to said automatic potential controller.

13. Apparatus as defined by claim 12 wherein said automatic potential controller is mounted on said platform.

14. Apparatus as defined by claim 12 wherein said supporting member is a water-tight conduit.

15. Apparatus as defined by claim 14 wherein said conduit comprises plastic pipe and said anode is mounted on the outer surface of said pipe.

16. Apparatus as defined by claim 14 wherein said conduit comprises a string of metallic pipe and a dielectric shield is positioned between said anode and the surface of said pipe.

17. An impressed current cathodic protection system for an underwater installation which comprises a supporting member provided with means for lowering said member into position adjacent said installation and later retrieving said member, an underwater power supply mounted in said supporting member for converting alternating current to low voltage direct current, at least one anode mounted on said supporting member, means in said supporting member for transmitting direct current from said underwater power supply to said anode, and means for transmitting high voltage alternating current from an underwater cable to said underwater power supply in said supporting member.

18. Apparatus as defined by claim 17 including a potential controller for regulating the direct current voltage applied to said anode, at least one reference cell for monitoring the potential difference between said anode and said underwater installation, and means for transmitting a signal from said reference cell to said potential controller.

19. Apparatus as defined by claim 18 wherein said potential controller is mounted in said supporting member.

20. Apparatus as defined by claim 18 wherein said reference cell is mounted on said supporting member.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,769,521 Dated October 30, 1973

Inventor(s) Joseph A. Caldwell, Gary D. Sump and Risque L. Benedict

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

In the Biographical Data: Assignee, between "Production" and "Company" insert --Research--. Abstract, line 5, delete "in" add--on--.

Signed and sealed this 5th day of November 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

FORM PO-1050 (10-69)

USCOMM-DC 60376-P69
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