United States Patent

Haycock

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[54] **CATHODIC PROTECTION OF CLOSELY SPACED OIL WELL CASINGS**

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[52] **U.S. Cl.** **204/147,** 204/196

[51] **Int. Cl.** **C23f 13/00**

[58] **Field of Search** 204/147, 196

[56] **References Cited**

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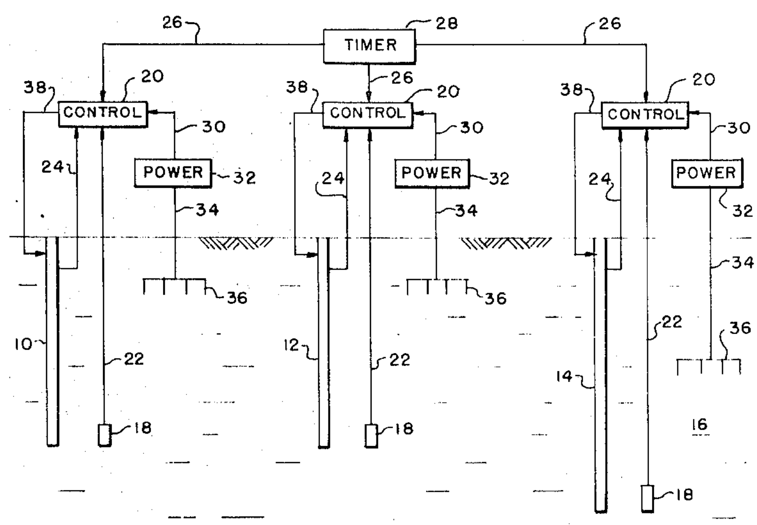
[57] **ABSTRACT**

A method of cathodically protecting a plurality of closely spaced oil well casings by maintaining the casings at a predetermined negative potential with short current pulses and so timing said pulses that they do not overlap and thereby create mutual interference.

3 Claims, 3 Drawing Figures



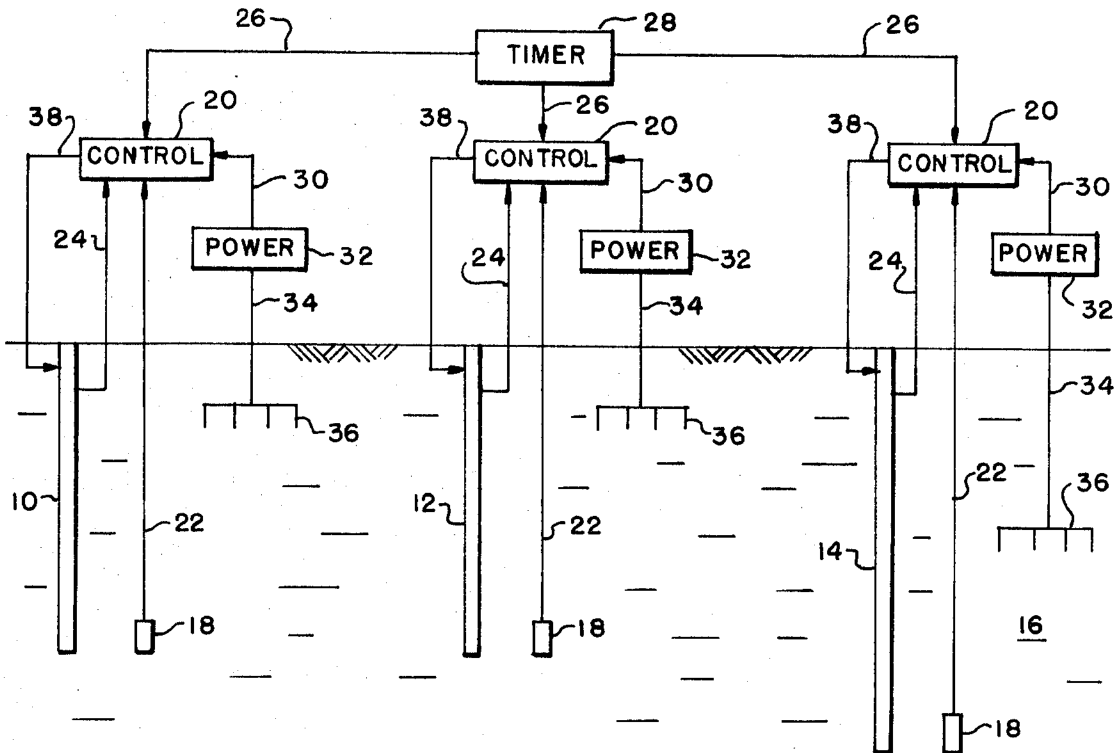


FIG. 1

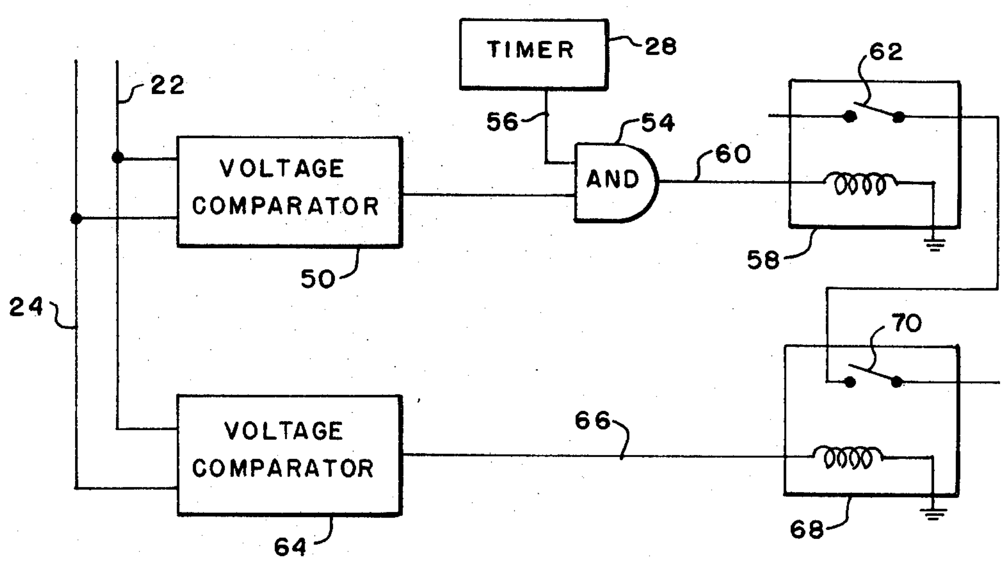


FIG. 2

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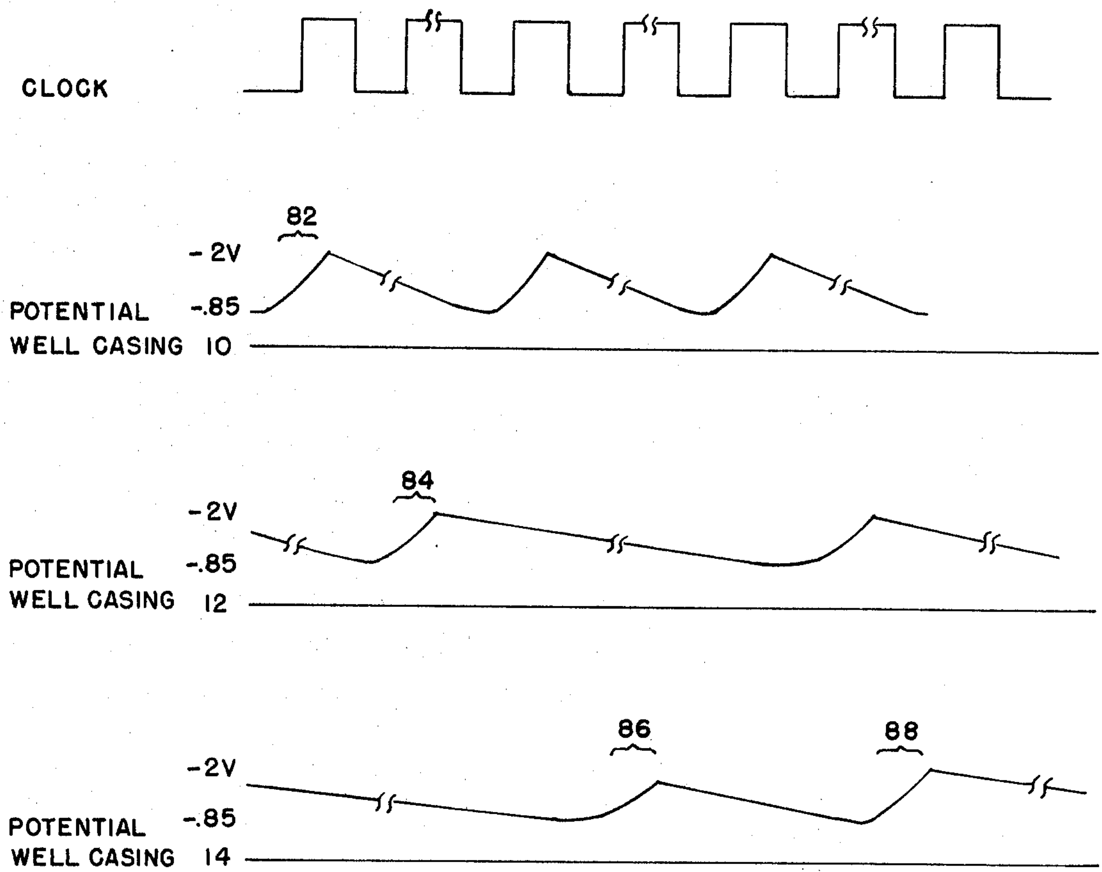

FIG. 3

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CATHODIC PROTECTION OF CLOSELY SPACED OIL WELL CASINGS

BACKGROUND OF THE INVENTION

This invention relates generally to the cathodic protection of many, closely spaced oil well casings. More particularly it relates to a technique for avoiding the problem of mutual interference among closely spaced well casings.

The background of this invention starts with the advent of corrosion prevention of well casings by cathodic protection — that is, the prevention of corrosion of electrolyte immersed metal surfaces by the impression thereon of an electric current. Although this technique has been very effective under certain conditions and has been used extensively for the past several decades, serious problems of mutual interference are encountered when oil wells are closely spaced. In some cases, mutual interference actually prevents the effective cathodic protection of an entire well casing, and in other cases it adds substantially to the cost of that protection.

By mutual interference among oil well casings is meant the effect on the current distribution of one cathodically protected oil well casing by the introduction of cathodic protection on other well casings in the area. The problem is that cathodically protected metal surfaces in a common electrolyte do not operate independently. The electric field of one cathodically protected structure interacts with the electric field of another to cause mutual interference. Or mutual interference may exist between different parts of the same cathodic protection system by the same mechanism. For example, mutual interference often occurs between different anodes in a multi-anode protection scheme.

If cathodic protection systems are very closely spaced, the effect of mutual interference may be to actually reduce the current output of one or more systems. As the spacing between systems becomes greater, the effect of mutual interference changes from actual current reduction of current distribution. Ultimately, if the systems are far enough removed, the effects of mutual interference are undetectable. Generalizations cannot be made about the distances between well casings necessary to cause one or the other effect. System geometries and soil conditions play an important role and may vary greatly. However, the effects of mutual interference have been observed where well spacings were in excess of 1,200 feet. And since many well spacings are significantly closer than that, the problems of mutual interference are serious in many oil fields.

The essence of the problem is that mutual interference reduces the effectiveness of cathodic protection. A cathodic protection system capable of protecting a well casing over its entire length will be inadequate when other cathodically protected wells are are placed near by. What often happens is that neither the original well casing or its new neighbor are fully protected over their entire length. Mutual interference prevents current from reaching the lower portions of either casing. And it is uneconomical or sometimes impossible to supply enough current to overcome this problem.

In the past, people have tried to solve the problem primarily by the careful physical location of the anodes of the cathodic protection system. However, this technique makes only a slight improvement. Indeed, the problem has not been solved. Thus, it is a primary objective of this invention to eliminate the problem of mutual interference from oil well casings.

SUMMARY OF THE INVENTION

These and other objects of the invention can be achieved by supplying a plurality of current pulses to the corrosion circuit in an amount sufficient to impose on the metal to be protected a negative voltage, the total amount of current delivered in each pulse being less than an amount sufficient to cause significant evolution of hydrogen gas from the metal surface. The pulse is repeated when the voltage on the metal surface, goes above a critical negative potential, in the case of steel, 0.85 volts with respect to the $Cu/CuSO_4$ reference electrode. The current pulses for each individual oil well casing are so timed as to not overlap the current pulses of any other nearby protection system. Alternatively, the current pulses for each well are allowed to operate with no external timing control. In this case the randomners of the pulses is such that the probability of mutual interference occuring is low.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 diagrammatically illustrates a typical apparatus for carrying out the general method of the subject invention.

FIG. 2 diagrammatically illustrates an embodiment of the controller of FIG. 2.

FIG. 3 is a plot of well casing potential as a function of time as it might appear when the present invention is utilized.

DESCRIPTION OF THE PREFERRED EMBODIMENT

To further understand the operation of this invention and how it fulfills its objectives, it is helpful to refer to the basic theory of cathodic protection.

The various environmental factors in underground corrosion contribute to differences in electric potential between one area of a metal surface and another. The resulting corrosion is the same whether caused by electric current impressed by an outside source or by minute currents developed due to these variations in environmental factors.

The mechanism of corrosion and the conditions that have to be fulfilled in preventing corrosion can be most readily understood by reference to the reactions in simple cells. Inasmuch as iron is the principle metal used in oil well casings, the iron reactions are of primary interest. Corrosion occurs at active places referred to as anodic areas which are electrically connected with less active or passive areas referred to as cathodic areas. An anode is an electrode from which electrons flow to an external circuit. Simultaneously, positive ions are formed at the anode metal-electrolyte interface. A cathode is an electrode to which electrons flow from an external circuit. It is at the anodes that corrosion takes place and in iron it takes place in accordance with the following reaction:

$$Fe \rightarrow Fe^{++} + 2e^-$$

In this part of the reaction, the iron metal atom Fe gives up two electrons, $2e^-$, becoming thereby positively charged iron ions Fe^{++} which go into solution in the electrolyte in contact with the iron area. The two electrons impart a negative charge to the iron anodic region and are thereby forced to flow in the metallic circuit toward the cathode.

A typical reaction at the cathode is as follows:

$$2H^+ + 2e^- \rightarrow 2H \rightarrow H_2$$

The consumption of H^+ at the cathode leaves a surplus of OH^- by virtue of the equilibrium

$$H^+ + OH^- \rightleftharpoons H_2O$$

The combination of Fe^{++} ions and two OH- ions to form a molecule of ferrous hydroxide accompanies the rest of the reactions and takes the Fe^{++} ions out of solution thereby maintaining electrical and chemical neutrality of the electrolyte. A more predominant cathode reaction in aerated corrosion systems combated by cathodic protection is the reduction of oxygen to form OH^- ions by the reaction

$$O_2 + 4e + 2H_2O \rightarrow 4OH^-$$

The overall anionic reaction is then:

$$Fe + 2OH^- \rightarrow Fe(OH)_2 + 2e^-$$

The overall cathodic reaction is usually a mixture of

$$2H^+ + 2e \rightarrow 2H \rightarrow H_2$$

and

$$O_2 + 2H_2O + 4e \rightarrow 4OH^-$$

The tendency of a metal to liberate electrons and to go as ions into solution in an electrolyte is related to the potential of the metal measured with reference to other elements. Potentials are expressed with reference to an arbitrarily designated zero potential of the normal hydrogen electrode.

Metal like iron corrodes less rapidly than the more active metals such as zinc and magnesium and more rapidly than silver or copper. In general, where two metals are connected together in a cell, the metal with the more negative potential will corrode in preference to the other. The corrosion reaction is driven by the total cell voltage, or difference of potential.

However, two different metals need not be present to form an electrochemical cell. Metals with areas at different activities may corrode. For example, an area of iron on a pipe that is better aerated than another will be less active.

Each of the electrodes in the electrolyte together with that portion of the electrolyte in immediate contact with the electrode comprises a half cell. The composition of the electrolyte when the current is flowing may vary from one part of the cell to another. The half cell potentials therefore will depend on the electrolyte condition at the respective electrode surfaces. These relationships of half cells, dependent upon electrolytic conditions, are characteristic of corrosion cells.

In theory, the corrosion reactions occurring at mutually dependent anodes and cathodes could be stopped by opening the electric circuit between the anode and cathode or by connecting the cell to an outside source of current opposing the voltage of the cell. The reaction can be stopped if the applied voltage is exactly equal to and opposite to that of the cell. Actually, local action due to impurities in iron and other practical conditions will cause iron to corrode to some extent even when the theoretical voltage is exactly balanced. However, the local action in the iron can be effectively stopped by increasing the applied voltage. This will put a surplus of electrons on the iron and convert the total surface of the iron in the electrolyte cell from that of anode to that of cathode. This is called cathodic protection of iron.

Typically cathodic protection is implemented by burying an anode some distance from the well casing to be protected and connecting a d.c. power source between the anode and well casing. Alternatively a sacrificial anode without an electrical power source may be used. In either case, an electric field is created between the anode and casing and it is through this field that the electrical effects of cathodic protection reach the casing. Thus, it is important that the electric field reach all parts of the casing. Where oil wells are widely spaced, this is rarely a problem. However, when wells are closely spaced as they are in many high production fields, the field caused by the various cathodic protection circuits interact with each other. This interaction often distorts the various fields so that they do not reach all parts of the casings and often greatly increases power requirements and cost.

The present invention solves this problem by supplying the electrical power to the cathodic protection circuits in short pulses which if supplied at appropriate intervals provides excellent cathodic protection. In addition, the pulses may be spaced so that no two pulses occur together.

Although the amplitude, duration and frequency of pulses necessary to provide good cathodic protection will vary considerably, a typical example would be a pulse that polarizes its well casing to minus 1.5 volts for 100 milliseconds. After a pulse is supplied the casing is allowed to depolarize until it reached a voltage level of minus 0.85 volts at which point another pulse is supplied. Times between pulses will again vary greatly, but times of 4–10 minutes are not uncommon.

At this point it might seem that having one cathodic circuit pulsed while others are off in a congested area would lead to stray current damage. The problem of stray current damage arises when current from some external source passes through a metal structure in electrolyte. Metal is forced into solution where the electrons enter the structure. However, it has been found that stray current in the form of pulses do not cause significant corrosion damage since any metal that is forced into solution while the current is on is plated back on when the current pulse ends.

In carrying out the method, two implementations may be used. The simplest and least expensive approach is to provide each well casing with independent pulsed cathodic protection system. Each well will supply a current pulse as the potential on that particular casing rises to minus 0.85 volts. Since the time at which any particular well casing reaches a potential of minus 0.85 volts is a random occurrence, current pulses will be supplied in a random pattern. And since the current pulse width is a relatively small proportion of the total pulse period, the probability that nearby well casings will receive pulses at the same time is very small.

Alternatively, a centrally controlled protection system may be employed. All well casings near enough together to experience mutual interference have their individual cathodic protection circuits controlled by a central timer. The current pulses for the various well casings are so timed that no two pulses are on simultaneously. Thus, mutual interference is completely eliminated.

FIG. 1 illustrates an apparatus for putting this method into practice. Referring now to FIG. 1, oil well casings **10**, **12**, and **14** are sunk into the earth **16** which acts as an electrolyte. Three wells have been illustrated for the sake of clarity although in practice there may be many more.

The electric potential of each oil well casing **10**, **12**, and **14** is compared against its own reference electrode **18**. A reference electrode is a half cell whose potential is known and is fixed. The reference electrode is necessary to provide a stable reference potential against which the potential of the casing can be compared. Examples of reference electrodes in common use are the $Cu/CuSO_4$ reference electrode, the $Pb/PbCl_2$ reference electrode, and Ag/AgCl reference electrode. In this patent application, all potentials are quoted with reference to the $Cu/CuSO_4$ reference electrode.

Each well is provided with a controller **20**. Reference electrodes **18** are connected to one input of **20** by leads **22**. A second input to controller **20** is connected via leads **24** to well casings **10**, **12**, and **14**. A third input to controller **20** is connected via leads **26** to a timer **28**. A fourth input to controller **20** is connected via leads **30** to one end of power supplies **32**. The other end of power supplies **32** is connected via leads **34** to anode beds **36**. Finally, the outputs of controllers **20** are connected via leads **38** back to well casings **10**, **12**, and **14**.

Controller **20** performs the following functions: First, it measures the voltage difference between the respective well casings and reference electrodes **18** — that is, between leads **22** and **24**. The controller then supplies output power via leads **38** when the measured voltage difference falls below a certain level such as 1 volt. However, the controller can supply output power only when the input voltage level is below 1 volt and when an enable signal is received from timer **28**.

Several hardware schemes capable of performing this function are known. FIG. 2 merely illustrates one possible approach. There, one voltage comparator **50** receives input from reference electrode lead **22** and well casing lead **24**. Comparator supplies a d.c. output on lead **52** whenever the difference in voltage on inputs **22** and **24** is less than 1 volt. Output **52** of comparator **50** is supplied to one input of AND circuit **54**. The other input of AND circuit **54** is connected to timer **28** via lead **56** when the output of comparator **50** is high and a signal is received from timer **28**; the output of AND circuit **54** actuates relay **58** via lead **60** so that switch **62** is closed.

Voltage comparator **64** supplies a d.c. output so long as the difference in voltage on inputs **22** and **24** is less than 2 volts. The output of comparator **64** is supplied via lead **66** to relay **68** and operates to maintain switch **70** closed so long as an output is present. Thus, the entire circuit operates to supply power via lead **38** starting when the voltage on leads **22** and **24** is less than 0.85 volt and until it reaches 2 volts.

FIG. 3 illustrates how the voltages on the three well casings might appear under the influence of the present invention. The vertical scale represents electrical potential in volts and the horizontal scale represents time. The clock pulse widths were rather arbitrarily chosen to be 10 milliseconds. The horizontal scale is broken at several points (horizontal slashes) to illustrate that the potential decay on the well casings takes substantially longer than illustrated — on the order of minutes. The potential on each well casing is raised when current to its respective cathodic protection circuit is supplied. As previously explained, current is supplied to only one well casing at any given time. Thus, in FIG. 3, times **82, 84** and **86** — times when potential is rising on one of the casings — do not overlap. If by chance a single current pulse is insufficient to bring the well casing potential to 2 volts, a second (and as many thereafter as necessary) current pulse will be supplied the next time an actuating pulse is received from timer **28**. In a typical system this will be only a matter of a few milliseconds later. This situation is illustrated by the potential curve for well casing **14** in FIG. **3** at times **86** and **88**.

I claim as my invention:

1. In a method of cathodically protecting a plurality of closely spaced oil well casings imbedded in the earth wherein a closed electric circuit is employed for each of said oil well casings, said electric circuit including the oil well casing, an anode, a power supply connected therebetween, and the earth, the steps of:

1. detecting the potential on a first one of said plurality of oil well casings;
2. comparing said potential with the potential of a reference electrode;

3. supplying a current pulse of predetermined width and amplitude to said closed electric circuit of said first well casing when said detected potential rises above a first predetermined level; and,
4. repeating steps (1), (2), and (3) above with respect to all of said closely spaced oil well casings such that a current pulse supplied to separate oil well casings does not overlap in time.

2. The method of claim **1** further characterized by:

1. repeating steps (1), (2), (3), and (4) of claim **1** for each of said casings until said detected potential is below a second predetermined level;
2. allowing the potential on each of said casings to decay up to said first predetermined level; and
3. repeating steps (1) and (2) of claim **2**.

3. The method of claim **2** wherein said first predetermined potential is −1 volt and said second predetermined potential is −2 volts.

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