WELL PUMPING CONTROL SYSTEM

Fig. 1

Transmitter

Overload Sensor

Motor Driven Timer

Power Source

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WELL PUMPING CONTROL SYSTEM

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ABSTRACT OF THE DISCLOSURE

In well pumping apparatus including multi-phase electric motors, power consumption apparatus sensing instantaneous power consumption including means for sensing overload as an indication of equipment failure to the single phasing of the motor; means also sensing minimum power consumption at selected intervals in the pumping cycle as an indication of inadequate fluid in the down-hole pumping apparatus; said means interrupting current to the motor on achieving alarm conditions.

This invention relates to a control system for oil well pumping apparatus, and more particularly relates to a power monitoring and control system wherein the apparatus controls power delivered to the pumping apparatus and further provides means for analysis of the oil well pumping apparatus.

Electrically pumped wells are commonly used for the recovery of petroleum products from formations having insufficient pressure to flow to the surface. One apparatus commonly used is the walking beam pumping apparatus whereby an electric motor oscillates a walking beam about a pivot and the horse head is reciprocated above the wellhead. The horse head is connected to a string of metallic members known in the trade as sucker rods which extend the full length of the well internally of the production tubing as a means of providing motive energy to the pump which is located near the producing formation. Since the details of the down-hole pumping apparatus are subject to some variation, and since they are provided with the present invention only by way of background, it will be appreciated that a survey of pumping apparatus is an aid to the description of the present invention.

Customarily, the fluid from the producing formation is lifted to the surface through the production tubing and is communicated to a gathering system whereby the fluid flows in a network of pipes extending to a collection point for handling in bulk by suitable means.

The power consumption of a producing well is usually substantial due to the fact that a producing well may be several thousand feet deep. While the weight of the sucker rods and pumping apparatus attached at one end of the walking beam is counterbalanced by weights either associated with the opposite end of the beam or else attached to a crank throw associated with the gear box and electric motor, it will be appreciated that substantial power is required at most wells. Since petroleum is customarily recovered from petroleum fields which are somewhat geographically compact, it has been noted that electrical power lines have been extended even to remote rural areas to provide the electrical power for pumping recovery. These electrical lines usually provide three phase electrical power which may be either 220 volts AC or even 440 volts AC. At any event, the horse power of the pumping motors is generally substantial and therefore, the motor is both expensive to operate properly and quite valuable in its own right. Moreover, the length of the lines and difficulty of voltage regulation introduces voltage fluctuations which are a problem to be dealt with by the present invention.

With a view of the economic worth of pumping apparatus generally found at oil wells, and with a further view of the problems of pumping oil wells, it can be appreciated that control apparatus is particularly economical in operation of electrically pumped oil wells. The present invention provides such a means.

Proper operation of a pumping well is particularly beneficial in the avoidance of damage to the apparatus. For instance, it will be obvious that an electric motor will burn up if overloaded. For instance, the pumping apparatus is customarily intended to operate with a fully charged pump resulting from an adequate fluid head from the producing formation. When the level of the fluid in the pump drops, the pump plungers compresses expanded gases in the top of the chamber above the pump and the pump contacts the surface of the liquid in a manner causing a condition known as “fluid pound.” The vibrations, oscillations, and structural shocks in the pump, sucker rods and production tubing are destructive to the equipment and may engender expensive repairs. Note should be taken of the fact that often the repair of downhole apparatus usually requires pulling the production tubing which is quite expensive. Therefore, one object of the present invention is to provide pump control apparatus for operating electric pumping apparatus only when fluid is available in the well bore in providing efficient operation to lift maximum fluid per unit cost of operation.

Another object of the present invention is to provide new and improved control apparatus for well pumping apparatus including means therewith for detection of electric motor overload conditions as indicated by excessive power consumption.

A related object of the present invention is to provide a new and improved control apparatus including means therewith detecting excessively low power consumption as an indicator of fluid pump off in the downhole pumping apparatus for shutting in the well to permit adequate accumulation of fluid from the producing formation.

An important object of the present invention is to provide new and improved control means for pumping apparatus preventing the electric motors from operating after loss of one or more phases of electric power supplied to the motor.

Other objects and advantages of the present invention will become more readily apparent from a consideration of the following specification and included drawings wherein:

FIG. 1 is a schematic block diagram showing the electrical apparatus of a pumping well connected with the circuit means of the present invention;
FIG. 2 is a schematic wiring diagram of the preferred form of the watt transducer adapted for use with the present invention;
FIG. 3 is a schematic wiring diagram of circuit means for sensing overload of the pumping apparatus;
FIG. 4 is a schematic wiring diagram illustrating means for sensing the power load during down stroke of the pumping apparatus; and
FIG. 5 is a schematic wiring diagram of pulse integrator circuit means. Attention is directed to FIG. 1 for a broad consideration of the means of the present invention. In FIG. 1, the motor for the pumping apparatus is indicated by the numeral 10. It will be appreciated that symbolic representation of the schematic of FIG. 1 is that of a delta wound resistive load intended only to be representative of the load placed on the three phase system to be described. The motor 10 is connected to a plurality of conductors indicated at 12 and includes the phase conductors 12-1, 12-2 and 12-3. The conductors are provided with a main circuit breaker means indicated generally at 14 which includes a relay operative device and a plurality of switches 14a interposed in the power delivering conductors provided to the motor 10. As a generalization, it should be noted that the well pumping apparatus including the motor 10 and the source of electrical power connected to the three phase distribution system indicated at 12 has interposed therewith power transfer means including the main breaker means 14 which interrupts power delivered to the motor 10. The control means is operatively connected to the power leads 12 to provide an indication of the power consumption. The power consumption monitoring means senses the consumption of the well pumping apparatus including the motor 10 to control the power consumption of the well pumping apparatus within predetermined limits and at selected time intervals as will be described in greater detail hereinafter.

Considering the invention more in detail, FIG. 1 illustrates watt transducer or signal multiplier means indicated generally at 16 which is operatively connected to the power leads 12 input to the motor 10. The power conductor 12-1 incorporates a current transformer 17 which provides an indication of the current flow in one phase to the transducer means 16. In addition, the conductors indicated at 18 provide the voltage between two phases, one of the phases being the phase conductor 12-1 so as to relate the current flow sensed by transformer 17 to the voltage input to the watt transducer means 16 with the proper phase angle therebetween. As understood by those skilled in the art, the watt transducer means 16 measures the power which is indicated by the well known relationship of voltage times current times the cosine of the phase angle. The output is a direct current signal on the conductor 20 which is provided to additional circuitry to be desired.

As will be appreciated by those skilled in the art, the watt transducer means 16 may be replaced alternatively with a double wattmeter arrangement whereby power is measured in two multiplier transducers and the direct current signals are summed. However, it will be appreciated that, with a generally symmetrical load such as a motor 10, the load on each phase is equal and therefore the arrangement shown in FIG. 1 is more economical. However, mention is made of more complex apparatus for measuring the wattage should it be desirable to connect three phase power measuring apparatus to the power input leads shown in FIG. 1.

The conductor 20 which provides the direct current signal of the transducer means 16 is supplied to a number of circuits for further utilization. For instance, the transmitter 22 which is shown connected to the conductor 20 is preferably a device providing telemetry ability whereby the analog signal of the wattage consumption is relayed to a central data collection point to be analyzed or stored for other purposes. As one embodiment, the transmitter 22 may include a tone modulated frequency modulated transmitter apparatus whereby the signal is provided on the modulated carrier for high quality transmission.

The conductor 20 is also provided as a signal input for overload sensor means indicated at 24. The overload sensor means provides a set point for contrast with the analog signal on the conductor 20 to obtain an indication of overload or excessive power demand by the motor 10. This can be indicative of a number of conditions to be described, and the reaction of the overload sensor means 24 is to provide an output signal to additional apparatus whereby the operation of the motor 10 is interrupted as a safety precaution. Briefly, the overload sensor means 24 provides a connection to the neutral return or as indicated in FIG. 1, a ground connection at 26. The ground 26 is connected by the overload sensor means 24 to a conductor 28 which extends to additional circuitry illustrated in FIG. 1. Briefly, the conductor 28 is the output of the overload sensor means and is communicated to various circuits to be described.

The conductor 20 is additionally provided as an input to the underload sensor means indicated generally at 30. The means 30 provides set point operation whereby power consumption of the motor 10 as indicated by the transducer means signal level is monitored, and on dropping below a predetermined level, the means 30 interrupts the motor because the underload power consumption of the motor is indicative of a lack of fluid in the well bore or a malfunction. The underload sensor means 30 is timed in operation relative to the pumping cycle by a pair of switches 31 and 32. Switches 31 and 32 relate the timing of the pumping apparatus to the present invention to the down stroke portion of the pumping cycle which varies the load on the motor 10.

To obtain proper timing of the operation of the underload sensor means 30 with respect to the actual down stroke of the pumping apparatus and minimum power consumption of the motor, the switches 31 and 32 are placed on the walking beam apparatus to gate the apparatus on during the down stroke. As drawn and as will be later described, the underload sensor means 30 is gated on when the switches are opened to define the orientation point.

The possibility of low fluid level in the pumping apparatus is properly ascertained every cycle or oscillation of the walking beam apparatus. Therefore, the underload sensor means 30 provides an indication during each pump stroke to additional circuitry to be described. The underload sensor means 30 inputs its signal to a pulse integrator 36 which does not time out as long as the underload sensor does not detect low power consumption indicative of fluid or gas pound, or a loss of volumetric efficiency of the apparatus. In addition, a thermoelectric timer circuit 38 is provided which is “in effect” a start delay timer which allows the apparatus to recharge and start pumping properly during the initial driving period. The timer 38 is normally closed preventing operation of the pulse integrator by shorting out the pulse integrator for an interval.

A shut-in timer 40 is provided with the apparatus of the present invention. Shut-in is the term applied to producing oil wells to indicate that period of time when the pumping equipment is not in operation. Shut-in is a requirement imposed on producing wells for several reasons. One important use of the shut-in timer is to allow time for recharging the well bore with fluid from the formation. Also, a well may be shut-in because the regulatory agency concerned with conservation of natural resources may limit the production of the well to a stated percentage of the calendar period in question so that the shut-in timer is necessary to accommodate such a regulation. In addition, reservoir engineers may determine that a shut-in cycle is necessary to enhance the production of the well to avoid prematurely depleting the formation and possibly damaging the formation and thereby reducing the total recovery from the formation. At any event, shut-in timing is sometimes required for producing wells and to this end, the motor driven timer 40 is provided as shown in FIG. 1. As will be appreciated, motor driven timers commercially are available and usually include a synchronous, clock driven mechanism adjustable set to provide the timing cycle desired. At any event, the timing
cycle selected for the motor driven timer 40 is within the purview of those skilled in the art and the schematic diagram of FIG. 1 is sufficient to indicate that the motor driven timer provides an actuation initiating the operation of the apparatus of the present invention.

The motor driven timer is provided with switch mechanisms 40b and 40c. Switch 40b provides a neutral (the neutral in the AC power distribution system as indicated as ground) to the pulse timer 36 and the start-up timer 38 through the conductor 41. The conductor 41 communicated through the switch 40a to an additional conductor 42 eventually connected to the overload sensor means 34. Again, it should be noted that the conductor 28 communicating with the overload sensor means is subject to interruption thereby but, as will be noted, the conductor 28 closes the neutral path for the power distribution apparatus. Switch 40b, during shut-in, interrupts the ground return for the integrator 36, timer 38 and a relay 44 which controls the main circuit breaker 14 which opens on loss of power. It should be noted that circuit breaker 14 and relay 44 are wired so that a continual flow of current is required to maintain operation of the pumping motor 10. An additional switch 40b provides a neutral return for the motor driven timer 40 which serves the function of self-latching the timer 40. The motor driven timer, at the end of its cycle, opens the switch 40b and thereby removes the neutral current to the motor driven timer to terminate its operation. In this regard, the motor driven timer is initiated by a short neutral pulse on the conductor 46 from the pulse integrator 36. The pulse on the conductor 46 operates the motor timer 40 sufficiently to return the switch 40b to self-latching position.

At this juncture an overall perspective of operation of the apparatus of the present invention is believed desirable. When the pumping apparatus including the electric motor 10 is started, the start-up of operation is initiated by the shut-in timer 40. The shut-in timer cooperates with relay circuitry to be described to place the main motor breaker 14 in an operative condition whereby the three phase power is delivered to the motor 10. The construction of the preferred embodiment provides a control apparatus whereby continued monitoring by the overload sensor means 24 and a favorable indication of nonexcessive power load indicated thereby is a prerequisite to continue operation of the main circuit breaker 14 interposed between the power source and the electric motor 10. Specifically, operation of the overload sensor singles the main circuit breaker 14 and opens the main breaker contacts interposed between the power source and the electric motor 10. Moreover, continued pumping is also conditioned on the start-up timer 38. It will be appreciated that the presence of various electrical and mechanical transients requires a sort period for stabilization whereby in the underload sensing means is essentially disabled. As previously noted, the start-up timer 38 provides a short circuit until the heating element of the relay "times out" to open the circuit. In addition, gate point is defined whereby the underload sensor means 30 cooperates with the pulse integrator 36 during each down stroke of the pumping apparatus to ascertain the magnitude of fluid pound as best indicated by power load relative to a selected level. Thus, in retrospect it will be understood that the relay circuitry to be described cooperates with the overload sensor means and the underload sensor means and the timer previously noted to maintain the main circuit breaker 14 in an "on" position when conditions indicated by the power consumption of the motor 10 are favorable. With this in view, the remainder of the relay circuitry and various introduced in FIG. 1. It will be described after which the circuits represented in block diagram form in FIG. 1 will be considered in greater detail.

The main circuit breaker 14 is provided with electrical power through the conductor 45 from the relay 44. Terminating the relay 44 the main breaker control relay, it will be noted that the relay 14 is provided with electrical power from a 110 volts source through the relay contacts 44a. When the relay 44 is in the energized condition, the connection is made whereby 110 volts is provided through the relay contacts 44a to the main breaker 14 to maintain it in the holding condition, it being noted that the conductor 45 provides the current to the relay 14 and the conductor 46 is a neutral return circuit. Operation of the relay 44 is Related to the transition of a neutral return circuit therefor. The neutral circuit provided for conducting the conductor 43 depends on the operation of the motor driven timer 40 including the switch 40a to the pumping position. The conductor 43 provides a return neutral through the contacts 40a and thence through the conductor 42.

Additional functions are accomplished by the circuitry of the present invention as will be described. Attention is next directed to a relay 48 and the connections provided therefor. Operation of the relay 48 switches relay contact 48b to provide electrical power to the trouble light 51. The relay contacts 48b are provided with 110 volts AC and during routine operations of the apparatus, the 110 volts AC is switched away from the overload light 51. In the illustrated position, the 110 volt power is provided by way of a conductor 53 to the heater element of the thermoelectric delay circuit 58. The conductor 53 provides the heater element with power when the heater circuit through the conductor 41 is completed by switch 40a. In addition, the conductor 53 provides electrical power through the relay contact 48b to conductor 54 which communicates with the motor driven timer 40. The power is provided to the shut-in timer 40 and, as previously noted, the power distribution circuit is completed through either conductors 46 or 47. Thus, it will be appreciated that the maintenance of the relay 48 with the contacts 48b in the illustrated condition energizes the above noted circuitry, while on the other hand, the operation of the relay 48 to the opposite position energizes the trouble light 51 and switches the pumping apparatus off.

As previously noted, the conductor 42 connected with the contacts 48a provide neutral paths for the timer 38, pulse integrator 36, and the relay 44.

The wiring of the relays of the present invention also incorporates the various switch elements of the motor driven timer 40. However, attention is re-directed to the motor driven timer 40 to disclose further details concerning the connection of the switches associated with the timer 40. As previously noted the switch 40a provides a neutral return for either the pulse integrator 36 and the thermoelectric timer 38 on the one hand, a non-pumping position energizes the trouble light 51 and the neutral on the conductor 42 is conditioned on the operative position of the relay 48 and the overload sensor means 24 as previously noted.

While an adequate understanding has been obtained concerning the present invention, attention is directed to additional detail drawings whereby the various circuits shown in block form will be described in greater detail. It is believed that greater revelation of the preferred embodiment will be useful. Of course, the details of the various blocks are subject to variation and it is intended only to disclose the preferred embodiment of the invention.

With this in mind, attention is first directed to FIG. 2 which illustrates the watt transducer means 16 in greater detail. In the first instance, it will be noted that the conductor 12-1 is provided in FIG. 2 to couple the signal indicative of current flow through the conductor 12-1 by way of the transformer 17 through the pair of conductors 17a and 17b to the means 16. In addition, the transducer 16 utilizes the voltage difference across the conductors indicated generally at 18. The voltage is meas-
ured between phases of conductors 12-1 and 12-2. A double pole, double throw switch 18f is provided to connect the voltages from the transformer 18b to the wattmeter 7 with proper polarity.

The input of the signal corresponding to the current flow in phase A is provided through the conductors 17a and 17e to the nodal points 16a and 16b. The points 16a and 16b are provided with a pair of resistors therebetween indicated at 16c and 16d. The voltage developed at the points 16a and 16b is a voltage analogous to or corresponding to the current flow through phase A of the three phase power distribution system connected with the well pumping apparatus. In addition, it will be noted that the resistors 16c and 16d do not comprise the only path between the nodal points 16a and 16b, rather, the diode circuitry to be described will also provide a path therebetween. It will be further noted that the voltage across the resistors 16c and 16d is a voltage corresponding not only to the current but it is timed in relation to the phase angle used in the conventional formula for calculation of power.

Without regard to the polarity of the signal or the instantaneous value of the voltage provided through the conductors 18, it will be noted that the signal is input through the nodal point 16e after being properly switched by the switch 18f. In addition, the switch 18f communicates with the nodal points provided by the resistors 16f which is a balancing potentiometer assuring a zero output for zero input conditions, taking into account the factor that diodes vary in voltage in the forward direction. In addition to the potentiometer 16f, resistors are provided at 16g and 16h on each side and the resistors communicate with nodal points indicated at 16i and 16k. The voltage at the two nodal points 16j and 16l is provided to filtering circuitry including the filtering capacitor 16m connected therebetween and the filtering choke 16n connected in the output leads. It will be appreciated that selected leads for the output signal of the watt transducer means 16 eliminate the need of filtering circuitry. For instance, the lead circuitry may include input filtering means.

Several diodes are indicated by reference numerals 16p-16w, inclusive, and are connected as illustrated.

Consider for a moment operation of the circuitry of FIG. 2. A voltage of some polarity is provided between the nodal point 16a and 16b. Assume for purposes of illustration that the point 16b is positive with respect to the point 16a. As previously noted, the factor relating the cosine of the phase angle is incorporated in the voltage between the point 16a and 16b. As the voltage provided through the conductors 18 increases, it is again proper to assume that the voltage input to the potentiometer 16f is positive with respect to the voltage at the nodal point 16c. In this event, the diodes 16p, 16q and 16r are blocked and therefore do not conduct. Moreover, the remaining eight (8) diodes are biased in the conducting direction and therefore do conduct. However, since the operational voltage range of the apparatus is such that the forward conduction of the diodes is reduced by the forward voltage drop, the diodes effectively provide a non-linear resistance. Thusly, the resistance in the forward direction is proportional to or dependent on the voltage between the nodal point 16a and 16b and is therefore proportional to the amplitude of the current provided by the pair of conductors 17e and 17g and indicative of the current flow in phase A of the three phase power distribution system. In this event, the forward drop is therefore made dependent on or proportional to the current flow in the power distribution apparatus.

This dependency on the current flow alters the voltage divider which provides the output signal of the means 16. This output signal is then provided by the pair of conductors 17a and 17g and indicative of the current flow at the variable resistor 16f whereby the series resistors cooperate with the variable resistors (the diodes which are conducting) to divide the signal so that the voltage drop between the nodal point 16a and 16b is varied in relation to the current flowing through the three phase distribution system, then the voltage between the nodal point 16a and 16b is therefore small. As a result of this very large series drop even though the diodes 16p and 16q are biased in the conducting direction and the net result is that a very small voltage appears between the points 16a and 16b. This is indicative of lower power consumption. Obviously, low power consumption is associated with a small current. On the other hand, large current would produce a large current flow through the diodes in the forward direction and the equivalent resistance of the diodes resulting from their conduction in the forward direction is therefore reduced. Since these diodes form a voltage divider cooperating with the resistors connected serially with the potentiometer 16f, then the output signal provided to the filtering circuitry is made larger. In this event, the signal output by the transducer is increased and is therefore again analogous to the power delivered by the three phase distribution system previously described.

As previously noted, the filtering circuit elements 16m and 16n are useful dependent on the type of apparatus connected with the circuit means of the present invention.

The output conductors are connected as illustrated in FIG. 2 with the additional conductor 20a serving as a ground connection. Since the signal is a DC analog signal, it is appropriate to utilize only one conductor representing the output of the means 16 in FIG. 1 whereas two conductors are shown on FIG. 2.

Attention is next directed to FIG. 3 of the drawings of the present invention for an understanding of the over load sensor means 24. In FIG. 3, the conductor 20 is the input for the analog signal from the means 16 previously described. Briefly, the overload sensor means serves as a set point circuit which latches on obtaining an input signal exceeding the set point whereby the circuitry maintains the latched condition until manually released from the latched condition. This is particularly desirable since the overload of the motor 10 may be cyclic or periodic and interspersed with intervals of acceptable power consumption less than the overload condition. However, damage can be done even in such circumstances. Therefore, it is desirable to provide a latched circuit which is operated by even a momentary overload to protect the motor so that proper maintenance can be given to the motor 10 and the well pumping apparatus. With this in view, it should be recognized that the circuit in FIG. 3 has a normally quiescent condition which is non-operative and operates only on obtaining an overload condition and remains latched until mechanically re-set.

The conductor 20 inputs the analog signal for contrast with a set point provided by a variable resistor 64. The resistor 64 is adjusted to some bias level for a transistor 65. The set point voltage from the resistor 64 and the signal from the conductor 20 are matched against one another to obtain indications of proper or improper operation of the motor 10. Connection of the conductor 28 to the conductor 28 is obtained by a self-latching relay 66. Specifically, operation of the relay 66 closes the relay contacts 66a which continues without interruption to provide the neutral to the conductor 28 to operate the circuitry previously discussed.

Considering now the circuitry shown in FIG. 3, attention is first directed to the input. The conductor 28 is provided with a series dropping resistor and diode indicated at 67 and 68. The transistor 65 obtains its negative supply voltage through series resistors 69 and 70 from the transistor 65 is derived through series coupling resistor 71 and input to a transistor 72. Transistor 72 has appropriate circuitry including resistors 73, resistor 74, and capacitor 75. The transistor 65 has an emitter supply through Zener diode 76 which also communicates with the base of a transistor 75. The collector of transistor 75 is communicated with the base of transistor 72.

The relay 66 is communicated through a switch 80 to provide latching power to the relay 66 directly from the
The circuit including the armature of the relay 66 and the collector of the transistor 72. In addition, the output of the switch 80 to the point illustrated in FIG. 3 communicated the switch 80 with the resistor 81 at one terminal and with the resistor 82 at the other terminal. The resistor 82 is serially connected with Zener diode 84 and series resistor 85 as a voltage source for the set point resistor 64 previously noted. In the quiescent condition (the relay 66 is not operated), the circuit attains conditions whereby transistor 65 is turned on sufficiently to saturate. This results from the negative supply provided through the resistor 85, the Zener diode 84, series resistor 82, and the B- supply. When the transistor 65 is conducting heavily, current flow through Zener diode 76 is sufficient to also provide an operating point to the transistor 75 whereby the transistor 75 is also approximately saturated. Heavy conduction of the transistor 75 results in a collector voltage which is very nearly zero. In addition, heavy conduction of the transistor 65 provides an approximate zero potential at its collector which is communicated to the quiescent point of a Zener 84. As the zero level on the collector of transistor 65 which is provided to the base of transistor 72 provides a voltage on the base which is somewhat positive with respect to the emitter voltage, and therefore, the base is reverses biased and the transistor is a non-conducting condition. Thus, transistor 72 is blocked and current flow is minimal. Because of this, no current flows through the armature of relay 66 and therefore the relay is in the non-energized condition.

These conditions may continue for an extended interval of time until the signal provided on the conductor 20 rises sufficiently to alter the conditions. As previously noted the negative bias provided by the set point adjustment at 64 is such that the transistor 65 is biased on. When a large positive voltage is provided through the conductor 20 and input to the base of the transistor 65, the transistor 65 is biased at an off condition and current flow is materially reduced. The interruption of current flow through the transistor 65 causes the collector voltage to decrease rapidly, approaching the B- potential. When the collector becomes quite negative, this negative voltage is coupled to the base of transistor 72. In like manner, the current flow through Zener diode 76 is materially decreased and the Zener diode conducts forward with a Zener drop. This changes the current flow through the collector circuitry of transistor 72 and the result of this change is that the emitter voltage of the transistor 72 is materially increased, thereby providing proper biasing for conduction through the transistor 72. The transistor 72 is turned on rapidly to pulse current through the collector circuitry of transistor 72. Since the collector of transistor 72 is connected to the armature of the relay 66, the heavy conduction energizes the relay and causes same to close the leaves of the magnetic bias relay and communicate conductor 25 with conductor 26.

It should be noted that the above described conduction of the circuitry is continued because current flow is adequate to Zener diode 84 to maintain conduction. Therefore, even a momentary signal on the conductor 20 indicating overload of the motor 10 is adequate to place the circuitry of the present invention in the latched condition.

The circuit can be re-set by the switch 80, it being noted that the switch 80 is preferably a hand-operated switch which is operated only after inspection of the apparatus of the well pumping equipment for defects and the like. When the switch 80 is operated, in effect, the resistor 82 is shorted and sufficient current flow across the shorted resistor through the Zener diode 84 enables the transistor 65 to re-obtain its set point bias. This bias, of course, maintains the circuitry in the original described condition preparatory to receiving another large signal on the conductor 20 indicative of an overload. Also, operation of the switch 80 interrupts current flow through the coil of the relay 66 and therefore allows the relay to open. Attention is next directed to FIG. 4 which illustrates the underload sensor means 30. The input to the underload sensor means 30 is against the analog signal from the watt transducer means 16 on the conductor 20. The circuitry of FIG. 4 is similar to the overload sensor means shown in FIG. 3; therefore, circuit elements of the underload sensor means 30 have been given reference numerals increased by one hundred in FIG. 4 corresponding to like parts of FIG. 3. Attention is directed, however, to two variations in the circuitry shown in FIG. 4. In one instance, the previously described switches 31 and 32 are connected by way of a conductor 188 to the base of the transistor 172 to input the gate time switching determined by the switches 31 and 32. In addition, the re-set switch has been eliminated from the underload sensor means 30, and the circuit connects conductors 90 and 91 together.

The underload sensor means shown in FIG. 4 provides set point operation whereby the set point is obtained from variation of the resistor 164 in the same manner as resistor 64 previously noted. Again, the signal on the conductor 20 is compared to the signal on the set point 164 so that the circuitry again operates in the same manner as the previously described circuitry including transistors 65, 72 and 75. Thus, operation of the circuitry results in current flow through the armature of the relay 166 resulting in closure of the relay contacts 166a and connection of the conductors 90 and 91.

Attention is next directed to FIG. 5 which illustrates the pulse integrating circuit means indicated generally by the numeral 36. Input conductors 90 and 91 are provided thereto and one of the pair of conductors is grounded. Briefly, the pulse timer circuitry indicated generally at 36 is designed to cooperate with underload sensor means 30 as a means for preventing fluid pumped in the downhole pumping apparatus. As was previously noted, a loss of fluid level in the downhole pumping apparatus reduces the power requirements of the pumping apparatus but causes damage to the pumping apparatus by excessively stressing the sucker rods and other equipment. The underload sensor means 30 (at the proper instant determined by the beam switches 31 and 32) analyzes the power delivered to the pumping motor 10 and provides an indication of low power consumption. Underload signals on the conductors 30 and 91 cause the pulse integrator means indicated generally at 36 in FIG. 5 to "time out" resulting in shut-in of the well. When the pulse timer 36 does time out, the closure of a relay contained therein provides a pulse through the conductor 46 to the motor driven timer 40 which initiates operation of the motor driven timer to shut in the well.

A consideration of the circuitry shown in FIG. 5 discloses an unijunction transistor oscillator manufactured by the Midland Standard Company with an adjustable time constant triggered by the signal on conductor 90. Specifically in FIG. 5, the diodes 100 and 101, the resistor 102, and the capacitor 103 cooperates to provide a DC voltage for charging an RC circuit. The capacitor 104 cooperates with the variable resistor 105 to provide the adjustable time constant for the trigger circuit shown in FIG. 5. Operating current is provided for the unijunction transistor 106 by means of resistors 107 and 108. AC signals are grounded by capacitor 109.

The input of the signal from the RC timing circuit is provided through series resistor 110 which is also connected to the conductor 90. As long as the conductor 90 is grounded, the RC timing circuit has no affect on the transistor and therefore the transistor is withheld from firing. However, if the conductor 90 is electrically disconnected from the fixed potential, and the input is free to follow the voltage provided by the RC timing circuit, the potential provided through the series resistor 110 increases to the unijunction transistor 106. When the transistor input signal achieves a predetermined level, trig-
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11. The control apparatus of the present invention is particularly useful in preventing the motor 10 from operating as a single phase motor. Multiple phase motors are known to attempt operation at lower speeds with a poorly distributed load on the motor and loss of electric power in one of the multiple phases. Thus, referring to FIG. 1, should the power in the conductor 12-3 be lost due to any one of a number of unforeseen circumstances, the motor would then attempt to run with current from the remaining two phases. It will be appreciated that this provides an uneven load on the motor and generally results in overheating of the windings associated with at least one phase of the motor. With a load of any size on the motor, the motor 10 may be destroyed by overheating.

The present invention is sensitive to single phasing of the motor and prevents operation in this manner. Should the power loss be in the conductor 12-3, the motor 10 will attempt to operate at approximately the same load conditions and an increase in current will be noted in the conductors 12-1 and 12-2. With the current transformer 17 placed in one of the two active phases, the increase in current is reflected to the transducer means 16 and the transducer means 16 indicates an overload condition to the overload sensory means 24. If either conductor 12-1 or 12-2 is interrupted by an unforeseen power failure, the loss of the potential difference obtained by the conductors 18 and supplied to the transducer means 16 results in an output indication similar to an underload which is detected by the underload sensor means 30 which also terminates operation of the motor 10. It will therefore be recognized that in both events, electric power to the motor 10 is terminated by opening the main circuit breaker 14 to prevent the motor 10 from operating on less than the intended number of phase voltages supplied thereto.

Many details have been omitted because they depend on the nature of the pumping apparatus, the pumping cycle and other factors subject to variations known and understood by those skilled in the art. For instance, the down stroke correlation of switches 31 and 32 to the apparatus is subject to variation. As one example, it might be possible to use positioned microswitches operable by movement of the reciprocating gear. This arrangement has only two moving parts (the vanes) and it has the further virtue of providing switch gear placed in an all weather housing.

What is claimed is:

1. Apparatus for use with pumped wells having an electric motor connected to a source of power, comprising:
   (a) watt transducer monitoring means adapted to operably connect to the power inputs of the well pumping apparatus;
   (b) power transfer means interposed between the well pumping apparatus and the source of power therefor for controllably interrupting power flow to the well pumping apparatus;
   (c) control means connected to said power transfer means and provided with a signal from said wattage monitoring means indicative of the power consumption of the well pumping apparatus to controllably interrupt the power supplied to the well pumping apparatus;
   (d) level sensor means connected to said transducer means for sensing power consumption below a predetermined level;
   (e) gating means for relating operation of said level sensor means to the down stroke of the well pumping apparatus;
   (f) said gating means enabling said level sensor means to interrupt said power transfer means on sensing power consumption below the predetermined level; and,
   (g) means for initiating the shut in of the well on sensing a phase shift in peak power consumption on the down stroke.

2. Apparatus for use with pumped wells having an electric motor connected to a source of power, comprising:
   (a) watt transducer monitoring means adapted to operably connect to the power input of the well pumping apparatus;
   (b) power transfer means interposed between the well pumping apparatus and the source of power therefor for controllably interrupting power flow to the well pumping apparatus;
   (c) control means connected to said power transfer means and provided with a signal from said wattage monitoring means indicative of the power consumption of the well pumping apparatus to controllably interrupt the power supplied to the well pumping apparatus;
   (d) and wherein said wattage means includes current transformer means communicated with one phase of a multiple phase power distribution system, and also includes means for providing a voltage measured between two phases of the multiple phase power distribution system to said power consumption monitoring means.

3. The invention of claim 2 wherein said wattage monitoring means is sensitive to loss of current flow through
one of the phases of the multiple phase power distribution system and operates said control means to interrupt power transfer by operation of said power transfer means to the well pumping apparatus to prevent damage thereto on loss of the one phase of the multiple phase power distribution system.

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