A fail-safe electrical system for controlling, from a remote location, the operation of hydraulic, pneumatic, and/or electric powered mechanisms, and for measuring pressures, temperatures, and any other parameter transducible to an electric parameter and indicating the values thereof on a display panel at the remote location. As employed with valves and pressures at an underwater oil, gas, or other fluid well, the system comprises a control station at a suitable surface location, an underwater or subsea station adjacent to the well, a single electric cable interconnecting the two stations, and additional single electric cables from the subsea station to each of the valves to be operated and each of the pressure locations to be monitored. Where the valves, chokes, or other elements of the well are hydraulically or pneumatically powered, the system involves solenoid valves preferably positioned in the subsea station to control the hydraulic or pneumatic pressure delivered to the elements, and where the valves are electrically powered they are controlled by suitable relays in their electric circuit. A specific system for controlling the operation of nine valves and for monitoring five pressures at a well’s Christmas tree is described, as also is a system for carrying out these procedures on a plurality of wells from a single control station.
FIG. 2A

THOUSANDS
BCD

HUNDREDS
BCD

TENS
BCD

D M

POWER SUPPLY $x_1$
(CONSTANT CURRENT)

(c) POWER SUPPLY $x_2$
(-) (15 VDC)

SYSTEM 1

SYSTEM 2

POWER SUPPLY $x_3$
(115 VDC)

115 VAC 60 CY

284a

72

250

284a

72

68

250

258

262

264

252

254

272

274

18

276

278

62

GO

SYSTEM 1

SYSTEM 2

56

56a

56b

270-1

270-2

56

266

56

268

250
FIG. 28

POWER SUPPLY 225 VDC
(-) (+)

ALL INDICATOR TUBES

ALL POWER BUFFERS
ALL BUFFER / STORAGES

ALL BCD / DECIMAL DECODER / DRIVERS
ALL "OR" CIRCUITS
"AND" CIRCUIT

POWER SUPPLY 4 VDC
(-) (+)

252 272 18

250

286b

52

280a 282a

270d

52

284

280b

254 274

TD 1

TD 2

TD 3

TD 4

286 280
INT. STATION SYSTEM 1 - SYSTEM 2 INDICATOR TUBE 412

POWER SUPPLY #3
(115 V DC)

POWER SUPPLY #4
(- (+) (225 V DC)

ALL INDICATOR TUBES

ALL POWER BUFFERS
ALL BUFFER/STORAGES
ALL BCD/DECMAL DECODER/DRIVERS
ALL "OR" CIRCUITS
"AND" CIRCUIT

POWER SUPPLY #5
(4V DC)

FIG. 5B
ELECTRIC REMOTE CONTROL SYSTEM FOR UNDERWATER WELLS

This is a continuation of application Ser. No. 38,656, filed May 19, 1970 and now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to electric remote control systems, and more particularly to such systems for controlling from a remote location the operation of valves, chokes, blow-out preventers, and other various functional elements associated with an oil or gas well, and for reading at the remote location the fluid pressures and temperatures, or any other parameter transducible to an electric parameter, present at the well. One specific embodiment of the invention is with underwater well Christmas trees and surface-located control stations.

The ever-increasing demand for greater supplies of petroleum and natural gas have caused the worldwide search for these resources to be directed more and more to the continental shelves and other offshore underwater areas in many locations throughout the world. For some time it has been common practice to drill offshore wells from surface platforms either floating or supported on pilings, etc., and to complete the wells with Christmas trees on these platforms. Such surface completions are undesirable from several standpoints, prominent among which are their hazard to navigation, their vulnerability to damage by storms or other adverse surface climatic conditions, and their negative esthetic appeal to certain sectors of the community.

To overcome these problems, equipment and techniques have been developed for completing offshore wells on the bottom or floor of the water body, but as the water depth increases the problems of controlling the valves and other components at the on-bottom site, and of monitoring the pressures, temperatures, etc. at that site become much greater. Divers and submersible vessels can be used for some of this work, but both are expensive and not infrequently prevented from performing their tasks because of intolerable surface conditions. Divers also are very limited as to the depth to which they can descend and carry out their tasks efficiently, and some of the offshore wells currently being drilled, as well as some of those under consideration, are in water depths far too great for diver operations.

Controlling the valves of the on-bottom completed well by remote means has been done prior to this invention, but because of the complex equipment employed, the problems of malfunction and even greater problems of correcting the malfunction, and the magnitude of expense, these remote systems have not come into significant use. Remote control systems for surface-completed wells, such as on offshore platforms or on land, also are plagued with the same problems of complexity, malfunction, expense, etc. that prevail beneath the water. Thus there is a genuine need for a remotely controllable, relative uncomplex, and highly reliable system for these purposes, and it is to this end that the present invention is directed.

Accordingly, one of the objects of this invention is to provide a system for remotely controlling the operation of valves, chokes, blow-out preventers, and other functional elements of an oil, gas, or other fluid well.

Another object of the present invention is to provide a system for monitoring at a remote location, the fluid pressures and temperatures, or any other parameter transducible to an electric parameter, in the annulus, tubing, the bores of the Christmas tree, flow lines, and any other passages of an oil, gas, or other fluid well.

Another object of the present invention is to provide a fail-safe electric system for controlling, from a remote location, the hydraulic, pneumatic or electric power utilized to open and close the valves, chokes, blow-out preventers, and all other similarly functioning elements of an underwater or surface located oil, gas, or other fluid well.

Still another object of the present invention is to provide a remotely operated, fail-safe control system for manipulating the valves, chokes, blow-out preventers, and other equipment at a plurality of underwater or surface located wells, and for monitoring fluid pressures and other parameters of the wells transducible to an electric parameter.

A still further object of the present invention is to provide a remotely operated, electric control and monitoring system with dual operating modes, the modes interconnected such that the system can be switched immediately from one to the other in the event either mode malfunctions.

SUMMARY OF THE INVENTION

Broadly considered, the present invention comprises an electrical system for remotely controlling the operation of hydraulic, pneumatic, and/or electric powered mechanisms, and for measuring pressures, temperatures, and any other parameter transducible to an electric parameter, at one location and reading out these measurements at a remote location. In a more specific sense, the invention comprises an electric system for controlling from a surface or otherwise remotely located station the operation of valves, chokes, blow-out preventers, and other manipulatable elements in or at an oil, gas or other fluid well, and for monitoring at the station the position of the valves and the fluid pressures, temperatures, etc. present in or at the well. The system controls the operation of the hydraulic and pneumatic powered valves, chokes, etc. through solenoid valves in the hydraulic or pneumatic lines, and controls electric powered valves, chokes, etc. through suitable relays or switches in their electrical power lines. In the described embodiments of the invention, the pressures, temperatures, etc. are transduced as resistances and these resistances read out as visually displayed numerical values. The invention includes a system for controlling and monitoring a single well, comprising a control station with a display panel for reading out the various conditions being monitored at the well, and a subsea station, adjacent the well, for housing the system's well-site components. The invention also includes a similar system for carrying out these same operations on a plurality of wells, in which case a separate subsea station is provided for each well and a single intermediate switching station is incorporated between these subsea stations and the surface station.

The stations are connected by a cable containing electrical conducting lines, the cable from the surface station to the intermediate station containing six conductors, and from the surface station or the intermediate station to the subsea station containing four conductors. Each of the valves of the tree, or of the several trees when more than one is involved, can be opened or closed and its position determined separately from
the others, and each of the fluid pressure, temperature or other transducer measurable parameters of the tree or trees can be read separately at the surface. The electrical system is connected to the valves, etc. such that it provides fail-safe operation thereof; thus if the system should malfunction, all of the valves, etc. will automatically move into their fail-safe position. Both the single tree and the multiple tree systems of the invention include a redundant or backup mode to which the system can be immediately switched in the event the primary mode malfunctions. No separate subsea power supply is required for the operation of the systems of this invention, for all operating power requirements are met by a surface source of electric power, such as 115 volts AC.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a diagrammatic illustration, partly in perspective and in section, of a system for controlling nine valves and reading five pressures at a single underwater oil or gas well Christmas tree according to this invention, including a representation of one form of display and control panel that could be used at the surface station.

FIGS. 2A through 2E, when properly positioned together, constitute a partial block, partial schematic representation of the electrical circuitry of the surface station in the system of FIG. 1.

FIG. 3 is a partial block, partial schematic representation of the electrical circuitry of a subsea station according to this invention.

FIG. 4 is a diagrammatic illustration, partly in perspective and in section, of a modified form of the system of FIGS. 1–3 for use in controlling the valves and reading the pressures at five Christmas trees from a single surface station.

FIGS. 5A through 5E, when properly positioned together, constitute a partial block, partial schematic representation of a portion of the electrical circuitry of the surface station in the system of FIG. 4.

FIG. 6 is a partial block, partial schematic representation of the electrical circuitry of the intermediate station of the system of FIG. 4.

**DESCRIPTION OF THE PREFERRED EMBODIMENTS SINGLE WELL SYSTEM**

FIGS. 1, 2A through 2E, and 3 illustrate a system 10 within the scope of this invention for controlling the operation of nine valves of, and monitoring pressures at five locations at, a single underwater oil, gas, or other fluid well. As FIG. 1 diagrammatically illustrates, this system 10 includes a control station 12 positioned at a suitable location, such as a land based facility, offshore floating platform, or other surface location, a subsea station 14 positioned adjacent the wellhead 16, a four-conductor electrical cable 18 connecting the control station 12 with the subsea station 14, a three-conductor electrical cable 20 connecting the subsea station with each of nine valves V1–V9 on the well's Christmas tree 24, and a two-conductor electrical cable 26 interconnecting the subsea station 14 with each of five transducers P1–P5 for measuring the pressure at the chosen location on the Christmas tree 24.

The system illustrated in FIG. 1 is designed to control two master valves V1 and V2 in the annulus bore of the tree, two master valves V3 and V4 in the first tubing bore, a wing valve V5 for this bore, two master valves V6 and V7 and a wing valve V8 in the other tubing bore, and a crossover valve V9. Pressure transducer P1 is positioned to respond to the pressure in the annulus bore between master valves V1 and V2. Pressure transducer P2 is positioned intermediate the master valves V3 and V4, and pressure transducer P3 is positioned intermediate the master valve V4 and the wing valve V5, to register the pressure at those intermediate points in the first tubing passage. Likewise, pressure transducer P4 is intermediate the master valves V6 and V7, and transducer P5 is intermediate the valves V7 and V8, to monitor the pressures in the second tubing passage. These relative positions of the valves V1 through V9, and the pressure transducers P1 through P5, are pictorially illustrated in the display panel 42 of the control station 12 in FIG. 1, wherein the annulus bore is shown at 30, the first tubing bore is shown at 32 and its flow line connection at 34, and the second tubing bore and its flow line connection are illustrated at 36, 38, respectively. The line 40, in which the crossover valve V9 is mounted, serves as a crossover passage between the lines 34, 38, and, of course, also between the flow lines 34a, 38a connected to these lines 34, 38.

The control stations display panel 42 includes the several components for visually indicating the condition of each of the valves V1 through V9, and the pressures at each of the pressure transducers P1 through P5, to facilitate proper control of the various tree functions by the operator. This display panel includes a valve identification light 44 for each of the valves V1 through V9 and associated therewith a valve indicator tube 46, such as a gas filled cold cathode indicator tube known in the art as a Nixie tube, which indicates the present position of the valve with which it is associated. In like manner, the display panel 42 includes a pressure identification light 48 and a pressure indicator tube 50, of the same type as tubes 46, for each of the pressure transducers P1 through P5 on the tree 24. As will be more fully described, this control system is designed to facilitate the updating of the information shown in the valve and pressure indicator tubes by a manual or automatic scanning operation, so that at any time the operator can observe the present condition of these elements and pressures by reading the display panel. The valve and pressure indicator lights are also designed to indicate the present position of the scan, thereby providing the operator with information as to what next must be done.

The display panel 42 also includes a single-step push-button switch 52 for manually controlling the scan of the valves and the pressure transducers, and an auto-step push-button switch 54 that, when depressed, causes the scan to be carried out automatically in a cyclic fashion through all of the valves and pressure transducers. The display panel 42 further includes a valve actuate push-button switch 56 for actuating the system to open or close a particular valve, a valve actuate indicator tube 66 to indicate what can be done to the valve at that time by pressing the switch 56, and a system change push-button switch 58 with mode identifying S1 and S2 indicator lights 60, 62, respectively, for changing the polarity of the system and indicating which of the two polar states or modes the system is in, i.e., the main system mode S1 or the redundant or backup system mode S2.

The system also includes a key locking switch 64 for preventing or permitting a valve operation to be exe-
cuted when the valve actuate switch 56 is depressed. A
d power switch 68 in the external 115 volt AC power line
70 is also included in the display panel 42, together
with a light 72 for indicating whether the power is on
or off, the switch facilitating turning the power on or
shutting it off as desired. Thus it is apparent that the
display panel 42 and the subpanel 41 make up the
subsea Christmas tree 24 with respect to the presen-
tial condition of the several valves and the pressure
transducers to which the system is connected, and af-
ords the operator a means for quickly and accurately
determining the conditions at the Christmas tree and
opening or closing the connected valves as he desires.

Operation and control of the valves at the tree 24,
and monitoring the pressures of the pressure transduc-
ers P1 through P5 at the tree, are achieved through a
unique and highly simplified electrical system that is
schematically illustrated in FIGS. 2A through 2E, and
3. That part of the system existent at the surface con-
tral station 12, including the circuits, lights, indicator
tubes, etc., of the display panel 42, is shown in FIGS.
2A through 2E, so that when these Figures are properly
placed together they represent the total circuitry of
the control station 12. The components and circuits of
the subsea station 14, and of the valves V1 through V9
and the pressure transducers P1 through P5, are shown
in FIG. 3. Thus, when FIGS. 2A through 2E and 3 are
placed together they form the complete circuit diagram
of the system for a single well according to this inven-
tion.

Referring first to FIG. 2A, external 115 volt AC 60
cycle power is brought into the surface station 12 by
a line 70 and connected to a digital volt meter (DVM) 80
that supplies a direct current output in the form of tens,
hundreds and thousands binary coded decimal (BCD).
A four-conductor line 82 connects the thousands BCD
output of the DVM 80 to a BCD-to-decimal decoder
driver 84 (FIG. 2C), such as a CML 9960 (available
from Fairchild Semiconductor Division of Fairchild
Camera and Instrument Corporation) that accepts
1-2-4-8 binary coded decimal inputs at integrated cir-
cuit signal levels and produces ten mutually exclusive
outputs that can directly control the ionizing potentials
of many gas filled cold cathode indicator tubes. Lines
86, 88, 90, 92 and 94 separately connect five outputs
of decoder driver 84 to the identification lights 48 of
pressure transducers P1 through P5, respectively, and
lines 96, 98, 100, 102 and 104 connect these same five
outputs to the valve actuate indicator tube 66 to indi-
cate when a pressure is being monitored. The nine
identification lights for valves V1 through V9 (FIG.
2C) are likewise connected by lines 106, 108, 110, 112,
114, 116, 118, 120 and 122 to nine separate outputs of
a second BCD-to-decimal decoder driver 124. Lines
126, 128, 130 and 132 separately connect four "OR"
circuits 134, 136, 138 and 140 to the four inputs of de-
coder driver 124, and each of these OR circuits is con-
ected by a line 142 to a single "AND" circuit 144 that
is connected to two additional outputs of the decoder
driver 84 by lines 146, 148. These two additional out-
puts are also connected to the valve actuate indicator
tube 66 by lines 150, 152.

Since the pressures at the Christmas tree normally
are read out as thousands and hundreds of pounds per
square inch (psi), the hundreds BCD output of the
DVM 80 is connected by a four conductor line 154
through a power buffer 156 (FIG. 2D) to sub-circuits
158, 160, 162, 164 and 166 for each of the pressure in-
dicator tubes for transducers P1 through P5, respec-
tively. Each of the circuits 160, 162, 164 and 166 is
identical with circuit 158 which includes, in series with
line 154, a buffer storage 168 such as a CML 9959 Buf-
ner Storage Element (available from Fairchild Semi-
conductor Division of Fairchild Camera and Instru-
ment Corporation) that consists of four gated-latch cir-
cuits and a common gate driver, a BCD-to-decimal
decoder driver 170, and a pressure indicator tube for the
pressure being monitored, in this case tube 50 for pres-
sure at transducer P1. In like manner, the pressure in
hundreds is indicated in the pressure indicator tubes by
signals from the tens BCD output of the DVM 80,
which signals are conveyed by a four conductor line
172 through a power buffer 174 to each of the circuits
176, 178, 180, 182 and 184. The circuit 176, with
which each of circuits 178, 180, 182 and 184 are iden-
tical, includes in series a buffer storage 186, a BCD-to-
decimal decoder driver 188, and the pressure indicator
tube 50. Each of these pressure indicator tubes are con-
nected to its corresponding identification light 48 by
lines 190, 192, 194, 196 and 198, respectively. These
lines 190, 192, 194, 196 and 198 connect the corre-
sponding decoder driver 84 output terminals for the
pressure transducer P1—P5 identification lights to the
corresponding buffer storages 168 in the circuits 158,
160, 162, 164 and 166, and also to the buffer storages
186 of the circuits 176, 178, 180, 182 and 184.

Thus the line 190 functions tell the buffer storages
168 and 186 to store the last received data until they
are in position to receive new data regarding the pres-
sure at pressure transducer P1, and the lines 192, 194,
196 and 198 perform identical functions with their cor-
responding buffer storages. Accordingly, when a signal
is directed to the identification light 48 for transducer
P1, this signal also is sent to buffer storages 168 and
186, with the result that this identification light illumi-
nates and the pressure indicator tubes 50 for P1 update
the data displayed to indicate the present pressure at
P1. When a signal is directed to any of the other identi-
fication lights of P2—P5, or for that matter of valves
V1—V9, the identification light of P1 does not illumi-
nate and the line 190 tells buffer storages 168 and 168
not to change output regardless of any change of input.

The OR circuits 134, 136, 138 and 140 are con-
nected in parallel by a line 200 to the power buffer 156
which, of course, serves to increase the current sup-
plied to the OR circuits, and also to the circuits 158,
160, 162, 164 and 166, from that supplied to it by the
hundreds BCD output of the DVM 80.

Each of the valve indicator tubes 46 is connected
through its individual circuit to the line 172 from the
ten BCD output of the DVM 80. As illustrated in FIG.
2E, the valve indicator tube 46 for valve V1 is designed
to indicate an "O" when the valve is open, a "C" when
the valve is closed, and an "M" when the valve is mov-
ing between opened and closed positions, these indicia
appearing on the tube in response to a current received
in the tube from line 172 through serially connected
buffer storage 204, BCD-to-decimal decoder 206, and
discrete resistors R1 through R9. These resistors are
grouped together in threees, with resistors R1, R2 and
R3 connected in parallel to the decoder driver 206 and
the contact of the indicator tube 46 for the in-
dicia O. Likewise the resistors R4, R5 and R6 are con-
nected in parallel between the decoder driver 206 and
the “C” input contact of the indicator tube 46, and resistors R7, R8 and R9 are connected in parallel between the decoder driver 206 and the M contact of the tube 46.

Similar to the interrelation between the pressure identification lights 48 and the pressure indicator tubes 50, each of the nine outputs of the BCD-to-decimal decoder driver 124 (FIG. 2C) going to the nine valve identification lights 44 is also connected to the buffer storage for the corresponding valve indicator tube, for example, line 106 from the BCD-to-decimal decoder driver 124 to the valve V1 identification light is connected by a line 208 to the buffer storage 204. In like manner, lines 210, 212, 214, 216, 218, 220, 222 and 224 interconnect lines 108, 110, 112, 114, 116 118, 120 and 122, respectively, with the buffer storages of the valve indicator tubes for valves V2 through V9, respectively. These lines 208-224 perform the same function for these valve identification lights and indicator tubes as do the lines 190-198 for their pressure identification lights and tubes. Accordingly, when the valve V1 identification light is illuminated the indicator tube for valve V1 is receiving new data, the valve identification lights for valves V2-V9 are off, and the indicator tubes for valves V2-V9 show the last received data from their respective valves. It is to be understood that the components of the subcircuit 202 are duplicated for each of the valve indicator tubes of the remaining eight valves V2 through V9, i.e., subcircuits 226, 228, 230, 232, 234, 236, 238 and 240.

Connected to the 115 volt AC power line 70 is a bus line 250 for providing power to the various components shown in FIGS. 2A and 2B on the control portion of the control station 12. These components include a power supply No. 1 for providing a constant current to the subsea station 14, a power supply No. 2 for providing 15 volt direct current to the subsea station 14, a power supply No. 3 for providing 115 volts direct current to the subsea station 14, a power supply No. 4 for providing 225 volts direct current to each of the valve and pressure indicator tubes, and a power supply No. 5 for providing four volts direct current to each of the power buffers, the buffer storage, the BCD-to-decimal decoder drives, the OR circuits, and to the AND circuit 144. Two lines 252, 254 in the four conductor electrical cable 18 are connected to the DVM 80, the line 254 running through the normally closed contact 56a of the valve actuate switch 56, and also including a variable resistor 256. Variable resistor 256 allows adjustment of the total resistance seen by the constant current power supply to account for different lengths of cable between the surface station and the subsea station. The positive side of the power supply No. 1 is connected by line 258 to the conductor 252, and the negative side of the power supply No. 1 is connected by line 260 to the conductor 254. A line 262 connects the common terminal of the power supply No. 2 to the conductor 254, and a line 264 connects parallel leads 266, 268 from the negative and positive contacts of the power supply No. 2 to the conductor 252. The lead 268 includes the normally open contact 56b of the valve actuate switch 56, and lines 266 and 268 go through a single pole-double throw contact of a double pole-double throw relay 270.

In order to provide a “back-up” for the system in the event of malfunction of any of the components at the subsea station or the Christmas tree, this invention in-
time delay relay 286 times out. After time delay relay 280 times out, time delay relay 286 is deactuated which deactuates relay 270 and the stepping switch steps to its next position as in the single step operation. When time delay relay 280 timed out it deenergized time delay relay 284. As relay 284 has a time delay after de-energizing this starts its timing cycle. When relay 270 deactuated, its normally closed contact 270 allowed time delay relay 272 to be actuated through the maintained contact of auto step switch 54. Time delay relay 284 now times out, unlocking DVM 80 so that it can process the information from the new stepping switch position. After time delay relay 282 times out, its normally closed contact 282a deactuates time delay relay 280. This closes contacts 280b and 280a which actuates time delay relay 284 and 286 and the sequence starts again. It will repeat until auto step switch 54 is released at which time it will complete the cycle it is on and stop.

One of the key features of the present invention is the provision of a switching module at the subshea station 14 to sequentially connect the surface station to each of the valves or other wellhead elements to which the system is connected, and then to the analog functions, i.e., the pressure transducers, employed for measuring the pressures, temperatures, or any other parameter which can be transduced to a resistance. As illustrated in FIG. 3, the switching module 300 comprises a pair of two-deck stepping switches 302, 304 having stepping coils 302c, 304c, respectively, and these switches 302, 304 are connected to the conductors 252, 272 in the cable 18. Stepping switch 302 is functional when the system 1-system 2 switch 58 is in the system 1 position, as illustrated in FIG. 2A, and stepping switch 304 functionally replaces stepping switch 302 when switch 58 is placed in the system 2 position, thereby reversing the polarity of the 115 volt direct current (DC) in lines 272 and 274 but maintaining the same polarity in lines 272b and 274b below contacts 326–5 through 326–8. Thus the stepping switches 302, 304, in conjunction with the system 1-system 2 switch 58, provide a back-up facility should either of systems 1 or 2 malfunction.

Decks 302a and 304a of the stepping switches 302, 304 each contain 18 contacts or switch positions, two positions for each of the valves V1–V9, with one of each pair of positions functioning to conduct current for opening the valve and the other position of the pair for closing the valve. The positions are arranged in alternate order sequentially on the decks 302a, 304a, so that when the switch is in the odd positions 1, 3, 5, etc., the valve to which the particular position is connected is conditioned for opening, and when the switch is in any of the even number positions 2, 4, 6, etc., the valve is conditioned for closing. The decks 302b, 304b of the stepping switches contain 23 contact positions, the first 18 affording sequential connection with the resistances connected to the valve limit switches to indicate valve position, and the last five affording sequential connection with the five pressure transducers P1–P5, respectively. These last five contacts of the switch is connected with pressure transducer P1, etc., with the last position 23 affording a circuit through pressure transducer P5.

The stepping switches 302, 304 are operated through step-actuate decoder modules 306, 308. The decoder module 306 includes a relay coil 310 for the relay contacts 310–1 of the deck 302a, a relay coil 312 for the relay contacts 312–1 of the deck 302a, diodes 314, 316 and zener diode 318 associated with the relay coil 310, diodes 320, 322 and zener diode 324 associated with the relay coil 312, and two contacts 326–1, 326–2 of a four pole, double throw relay 326. Similarly, decoder module 308 includes coil 328a of a double pole, single throw relay with contacts 328–1, a coil 330 of a single pole, single throw relay with contacts 330–1, diodes 332 and 334, and zener diode 336 associated with the coil 328, diodes 338, 340 and zener diode 342 associated with the coil 330, and contacts 326–3 and 326–4 of the relay 326.

These step-actuate decoder modules 306, 308 accept a plus or minus fifteen volt DC signal from the conductors 252, 254 of the cable 18, and function to advance the switching module or open and close the valves.

When the polarity on line 252 is a positive 15 volts relay 310 is actuated, contact 310–1 is closed and 115 volts DC is applied through stepping switch deck 302a to open or close a valve. When the polarity on line 252 is a negative 15 volts relay 312 is actuated, contact 312–1 is closed and 115 volts DC is applied to stepper switch coil 302c to cock the stepping switch. When the negative 15 volts is removed from line 252 the stepping switch coil 302c is deenergized and the stepping switch advances to the next position.

Relay 326, which is operated by a positive 115 volt DC signal on the conductor 272 of the cable 18 coming from the surface station system 1-system 2 switch 58, governs which decoder module 306, 308 is functionally included within the over-all control system at a given time, and hence which stepping switch 302, 304 will be employed to operate the valves V1–V9 and monitor the pressure transducers P1–P5.

Using the conditions of FIG. 3 to illustrate, when a 15 volt signal is introduced into the conduit 252 by pressing the surface station actuate switch 56, this signal is received by decoder module 306 and energizes either the relay 310 which allows 115 volts to open or close the valve, or the relay 312 which advances the stepping switch one step.

In this embodiment of the invention, the valves V1–V9 are shown as hydraulically powered, and the control of their operation is facilitated by the functioning of a solenoid valve 350–1, etc., in their hydraulic lines. It should be understood that pneumatic or electric powered valves also can be controlled with the system of this invention, the pneumatic in the same manner as the hydraulic, and the electric by means of a suitable relay or the like in the circuit to its motor.

The control of these solenoid valves, and also the manner by which the position of the valves V1–V9 can be determined, is illustrated in FIG. 3 which depicts the circuitry to valves V1–V9. Referring to the illustrated circuit for valve V1, the solenoid valve 350–1 positioned in the hydraulic line 352–1 is connected to the system 1-system 2 115 volt direct current circuit by lines 354–1, 356–1 that connect with relay contacts 326–5, 326–6, 326–7, and 326–8, which in turn are connected to contact 10 of coil 324. A double pole, single throw relay 358–1, with one set of contacts 358–1a in the line 356–1 and the other set of contacts 358–1b in a line 360–1 that interconnects the lines 356–1 and 354–1 and includes the relay 358–1, is operatively connected to the first and second positions of the stepping switch decks 302a, 304a by lines 362–1, 364–1, respectively. This valve operating subcircuit also includes a
diode 366-1 between the lines 354-1, 356-1, and another diode 368-1 between the lines 364-1, 362-1, and a resistor 370-1 in the line 360-1 between the relay 358-1 and the line 354-1.

Accordingly, with the valve V1 in its closed position and stepping switch 302 or 304 in its first position (as illustrated in FIG. 3), the valve can be opened by pressing the actuate switch 56 at the surface station, thus sending a 15 volt signal on the conduit 252 to the relay 310 in the decoder module 306, energizing this relay and closing its contacts 310-1 to allow a 115 volt DC signal from conductor 274 to go through position 1 of stepping switch deck 302a and line 362-1 to the valve relay 358-1, closing contacts 358-1a and 358-1b. Once energized, the relay 358-1 electrically latches itself in the energized condition and allows a 115 volt signal across the solenoid valve 350-1, opening this valve and allowing hydraulic pressure in the line 352-1 to move valve V1 into its open position. Valve V1 will stay in this open position until it receives a signal to close, or the 115 volt signal is removed from the subsea station, this latter providing a "fail-safe" protection for the underwater tree and wellhead.

When the stepping switches 302, 304 are in position 2, and valve V1 is open, pressing the actuate switch 56 at the surface station will cause this valve to close. The 15 volt signal arriving at the subsea station on conduit 252 in the same fashion energizes relay 310, which closes and allows a 115 volt signal to be conducted by the line 364-1 to the relay coil 358-1. Both sides of the coil are at the same potential and the current in the coil falls to zero. This deenergizes the valve relay 358-1, thereby deenergizing the solenoid valve 350-1 which then changes position to vent or relieve the hydraulic force in the line 352-1, thus permitting the valve V1 to close. Of course, once closed, the valve V1 will remain closed until it receives another signal to open.

In order to determine whether the valve V1 is open, closed, or some position in between open and closed, the valve is provided with a limit switch 372-1 to indicate its fully opened position, and 374-1 that indicates its fully closed position. Each of these two limit switches has a fixed resistor in series with its contacts, and the resistor 372-1R is a different value than the resistor 374-1R. A third fixed resistor 376-1R is connected across the series combination of the limit switches and their resistors, so that when the valve is somewhere between fully open and fully closed, neither limit switch is closed and the third resistor 376-1R is the only one which can be measured externally. The values of the resistance of these three resistors are chosen so that the total measured resistance between resistors 372-1R and 376-1R in parallel is distinguishable from the total resistance between resistors 374-1R and 376-1R parallel, and so that the resistance through just the resistor 376-1R is distinguishable from either of the two foregoing measurements. Accordingly, when the valve is fully closed so that the limit switch 374-1 is closed, and the stepping switch 302 is in position No. 1 (FIG. 3), a voltage unique to the resistances of resistors 374-1R and 376-1R will be conducted through line 378-1 to common line 380 interconnecting the first positions on stepping switch decks 302b, 304b, and then to position 1 of stepping deck 302b and on to conductor 254 of cable 18, from whence it goes to the digital voltmeter 80 at the surface station and is ultimately read out in the valve actuator tube 46 for valve 1 as a C, and in the valve actuator indication tube 66 as an O to indicate that valve 1 is in condition to be opened by pressing the valve actuate push button 56. In similar manner, when valve V1 is fully opened so that limit switch 372-1 is closed, and the stepping switches are in the No. 2 position, the unique voltage across parallel resistors 372-1R and 376-1R will be conducted by line 382-1 to line 384 that is common to positions 2 on stepping switch decks 302b, 304b, and through the switch, the conductor 254, the digital voltmeter 80, and to the valve indicator tube 46 where it will be read out as an O and the valve actuate indication tube 66 where it will appear as a C, indicating that the valve is in position to be closed by the valve actuate switch 56.

When valve V1 is between opened and closed, the unique voltage across resistor 376-1R will be conducted by line 382-1 to common line 384 and thence to position 2 of the stepping switch decks 302b, 304b. If the stepping switches are in position 2, this unique voltage will then be readable at the valve V1 indicator tube as an M, and will still be readable at the valve actuate indication tube 66 as a C indicating that at this moment the stepping switch is in the position where valve V1 can be closed.

In order to distinguish each of the three possible positions of each of the valves from one another, the resistances of resistors 372-1R through 376-9R are selected to fall within a first range, the resistances of resistors 374-1R through 374-9R are chosen to fall within a second range, and the resistances of resistors 376-1R through 376-9R are selected to fall within a third range. Furthermore, to identify each of the 18 switch positions assigned to opening or closing the valves V1-V9, a unique resistor 386-1R is positioned in series with the aforementioned combination of resistors 372-1R, 374-1R, 376-1R and the contact position 1 of the stepping switch decks 302b, 304b, and another unique resistor 388-1R is positioned in series with the resistors 372-1R, 374-1R, 376-1R and the contact position 2 of the stepping decks 302b, 304b.

To illustrate the foregoing system for determining by unique resistances whether the valve V1 is open, closed, or at some position therebetween, resistors of 35.7 ohms for 372-1R, 156 ohms for 374-1R, 84.5 ohms for 376-1R, 2100 ohms for 386-1R, and 1100 ohms for 388-1R are used for those elements respectively in the valve V1 system. Accordingly, with the stepping switch 302b in the No. 1 position, a resistance reading in the range of 2110 to 2139 ohms will be obtained when the valve is in fully opened position, in the range of 2140 to 2169 ohms when the valve is fully closed, and in the range of 2170 to 2199 ohms when the valve is at some intermediate position between open and closed. The nominal resistance within these ranges is 2125, 2155, and 2185 ohms, respectively. The range allows for variations due to resistance tolerance, temperature change, and other normal variations.

As will be observed from the schematic of the surface station, the thousands digit of the above resistance readings is converted to a binary coded decimal in the DVM 80, and this decimal then fed to the valve actuate indicator tube 66 so that it indicates an O i.e., that the valve can be opened. The hundreds digit of these resistance readings is converted to a binary coded decimal at the DVM 80, and this decimal utilized to illuminate the valve V1 identification light 44, signifying that it is valve V1 which is being monitored and to send a signal.
to buffer storage 204 to allow updating of indicator tube 46 for this valve. In similar fashion, the tens digit of these resistance readings is converted to a binary coded decimal at the DVM 80, and this decimal then fed into the valve Vi indicator tube 46 where it indicates an O, C, or M, depending upon whether it is in the range of 1-3, 4-6, or 7-9, respectively. The units digit of these resistance readings are not considered significant, and are disregarded.

When the switch 302b is stepped to position 2, which position has been assigned to close valve V1, the resistance values readable at that position will lie in the range of 0 to 1139 ohms for open position, 1140 to 1169 ohms for closed position, and 1170 to 1199 ohms for an intermediate position. Thus, only the thousands digit has changed from the resistance values readable at switch position 1, and this change signifies that the valve can be closed in this switch position, the digit 1 being converted to a binary coded decimal in the DVM 80 and the decimal coded numeral fed to the valve actuate indicator tube so that it indicates a C.

The following Table I lists an operable set of resistor values that has been found to provide satisfactory results for the foregoing purpose. It is to be understood, however, that other values can be used within the scope of this invention, so long as they result in unique resistance readings sufficient to distinguish the valve position by whatever read-out device is employed.

| TABLE I |
| Resistor Values
| Omhs |
|---|---|
| 372-1 through 372-9 | 35.7 |
| 374-1 through 374-9 | 156 |
| 376-1 through 376-9 | 84.5 |
| 386-1 | 2100 |
| 386-2 | 2200 |
| 386-3 | 2300 |
| 386-4 | 2400 |
| 386-5 | 2500 |
| 386-6 | 2600 |
| 386-7 | 2700 |
| 386-8 | 2800 |
| 386-9 | 2900 |
| 388-1 | 1100 |
| 388-2 | 1200 |
| 388-3 | 1300 |
| 388-4 | 1400 |
| 388-5 | 1500 |
| 388-6 | 1600 |
| 388-7 | 1700 |
| 388-8 | 1800 |
| 388-9 | 1900 |

Using a system of resistors set forth in the foregoing Table I, the following Table II lists the resistance values and valve read-outs.

| TABLE II |
| Resistance Values and Valve Read-Outs |
|---|---|---|---|---|
| Switching Module |
| Resistance Range |
| Valve Function (Thousands digit) |
| Valve Displayed (Hundreds digit) |
| Valve Position (Tens digit) |
| Position No. | Ohms | O | 1 | O |
|---|---|---|---|---|---|---|
| 1 | 2110-2139 | O | 1 | O |
| 1 | 2140-2169 | O | 1 | O |
| 2 | 2170-2199 | O | 1 | O |
| 2 | 2110-2139 | C | 1 | C |
| 2 | 2140-2169 | C | 1 | C |
| 2 | 2170-2199 | C | 1 | C |
| 3 | 2210-2239 | O | 2 | O |
| 3 | 2240-2269 | O | 2 | O |
| 3 | 2270-2299 | O | 2 | O |
| 4 | 2120-2139 | C | 2 | C |
| 4 | 2140-2169 | C | 2 | C |
| 4 | 2170-2199 | C | 2 | C |
| 5 | 2310-2339 | O | 3 | O |
| 5 | 2340-2369 | O | 3 | O |
| 5 | 2370-2399 | O | 3 | O |
| 6 | 2130-2339 | C | 3 | C |
| 6 | 2140-2169 | C | 3 | C |
| 6 | 2170-2199 | C | 3 | C |
| 7 | 2410-2439 | O | 4 | O |
| 7 | 2440-2469 | O | 4 | O |
| 7 | 2470-2499 | O | 4 | O |
| 8 | 1410-1439 | C | 4 | C |
| 8 | 1440-1469 | C | 4 | C |
| 8 | 1470-1499 | C | 4 | C |
| 9 | 2510-2539 | O | 5 | O |
| 9 | 2540-2569 | O | 5 | O |
| 9 | 2570-2599 | O | 5 | O |
| 10 | 1510-1539 | C | 5 | C |
| 10 | 1540-1569 | C | 5 | C |
| 10 | 1570-1599 | C | 5 | C |
| 11 | 2610-2639 | O | 6 | O |
| 11 | 2640-2669 | O | 6 | O |
| 11 | 2670-2699 | O | 6 | O |
| 12 | 1610-1639 | C | 6 | C |
| 12 | 1640-1669 | C | 6 | C |
| 12 | 1670-1699 | C | 6 | C |
| 13 | 2710-2739 | O | 7 | O |
| 13 | 2740-2769 | O | 7 | O |
| 13 | 2770-2799 | O | 7 | O |
| 14 | 2710-2739 | C | 7 | C |
| 14 | 2740-2769 | C | 7 | C |
| 14 | 2770-2799 | C | 7 | C |
| 15 | 2810-2839 | O | 8 | O |
| 15 | 2840-2869 | O | 8 | O |
| 15 | 2870-2899 | O | 8 | O |
| 16 | 1810-1839 | C | 8 | O |
As indicated in FIG. 3, for the sake of simplicity and continuity the elements of the subcircuit of valve V9 are given numbers corresponding to their counterparts in the subcircuit of valve V1, and this procedure is followed in the above Table I.

Positions 19 through 23 on decks 302b, 304b of stepping switches 302, 304 are used to monitor the analog functions P1 through P5, and thus to read the pressures measured by those functions. As previously explained, for measuring these pressures the analog functions comprise pressure transducers, each of which has a resistance output proportional to the pressure it is measuring. In a control system where pressures up to a maximum of 5000 psi are to be read, variable resistors with an output of 0 to 500 ohms have been found satisfactory. It should be understood, however, that satisfactory resistance can be selected for any pressure range desired to be monitored.

As illustrated in FIG. 3, in series with each of the variable resistors 390–1R, 390–2R, 390–3R, 390–4R, and 390–5R is a fixed resistance 392–1R, 392–2R, 392–3R, 392–4R, and 392–5R, respectively, that will identify the analog function. An operable set of resistors found satisfactory for this purpose comprises 3000 ohms for 392–1R, 4000 ohms for 392–2R, 5000 ohms for 392–3R, 6000 ohms for 392–4R, and 7000 ohms for 392–5R. Thus, if the pressure at transducer P1 was 2500 psi, the resistance read-out would be 3250 ohms, whereas if that same pressure were present at transducer P2 the read-out would be 4250 ohms, and similarly 1000 ohms higher for each of the other three transducers.

At the surface station the resistance values are converted into a binary coded decimal at the DVM 80, the thousands digit identifying the analog pressure function P1 by illuminating the P1 identification light 48, the hundreds digit identifying the most significant pressure digit (thousands of psi) at the P1 thousand indicator pressure tube, and the tens digit identifying the second most significant pressure digit (hundreds of psi) in the P1 hundred pressure indicator tube, while the units is disregarded as insignificant. Thus, for a resistance read-out of 3250 ohms, the P1 identification light would be illuminated and the pressure indicator tubes for the P1 transducer would show 25. Two fixed zeros are present at the display panel 42 to indicate, in combination with the digits appearing on the tubes 50, the actual pressure present at the transducer, in this instance 2500.

The display panel 42 of this embodiment of the invention shows the latest position of the valves and the last pressures monitored by the analog functions, as well as the position of the switching module. Thus, when the power is turned on by pressing the power switch 68, the identification light of the valve or pressure analog connected to the surface station 12 by the subsea station switching module 300 and the cable 18 will be illuminated. If the switching module is connected to a valve, the valve actuate indicator tube 66 will display the position to which the valve can be moved. When the switching module is stepped to a different valve, the position of that valve is then indicated on the appropriate valve indicator tube 46, and the condition of the system with regard to operation of that valve is indicated in the valve actuate indicator tube 66. When the switching module is connected to a pressure transducer, the valve actuate indicator tube will display a P and the pressure valve will be displayed on the appropriate pressure indicator tube. To supply the latest information to the display panel, the operator merely presses the auto step switch 54, causing the system to cycle through each of the positions on the switching module 300 and update the display panel. If desired, the updating also can be accomplished by repeatedly pressing the single step switch 52, and of course a circuit for automatically scanning the valves and pressure analog values can be included.

**MULTIPLE WELL SYSTEM**

The foregoing described single well system 10 can be modified for use to control the valves, etc., and monitor pressures, etc., at a plurality of underwater wells. Broadly considered, and as diagrammatically illustrated in FIG. 4, the modified or multiple well system 10a involves the addition of an intermediate station 400 at a convenient location approximate the wells, such as adjacent one of the trees or generally equidistant all the trees, and the addition of a switching system at the surface control station 12a for operating a switching system at the intermediate station to connect the surface station to the desired underwater well. The surface station display panel is enlarged in the illustrated embodiment to include a separate display panel 42a for each of the trees to which the system is connected, and the addition of the required indicator lights and tubes for indicating the position of the intermediate station, and appropriate push-button switches and indicator lights for actuating the stepping of the intermediate station from one position to another. In the following description, the components of this multiple well system 10a which are identical to the components of the single well system 10 are designated by the same numeral for the sake of simplicity and clarity. Where the components only partially differ, the reference numeral is retained but distinguished by a small letter, and where the components are entirely different new reference numerals are applied thereto.
As shown in FIG. 4, the cable 18a between the surface station 12a and the intermediate station 400 includes 6 electrical conductor lines, and the cable 18b from the intermediate station 400 to the subsea station 14 has four electrical conductor lines as does the cable 18 of the single tree system. In a five well system as represented herein, each of the five Christmas trees 24–1, 24–2, 24–3, 24–4, and 24–5, has its own subsea station 14–1, 14–2, 14–3, 14–4, and 14–5, respectively, and each of these subsea stations is connected to the intermediate station 400 by its cable 18b–1, 18b–2, 18b–3, 18b–4, and 18b–5, respectively. Each of the five trees also is connected into its display panel 42a at the surface station 12a, of which only the display panel for tree 24–1 is shown in FIG. 4.

In addition to the single step, auto-step, and valve actuate push-button switches 52, 54, 56, key-lock switch 64, power switch 68, and indicator light 72, display panel 42b at the surface station includes an identification light 402 and a system 1-system 2 indicator tube 404 for each of the trees, a tree system 1-system 2 actuate indicator tube 413, and a tree system change actuate push-button switch 560. This panel also contains a single-step switch 406 and an auto-step switch 408 for stepping the intermediate station from one tree to another, a system-change push-button switch 410, and a system 1-system 2 indicator tube 412 for the intermediate station.

FIGS. 5A through 5E in combination with FIG. 2E illustrate the electrical circuitry of the well subsystem 10a surface control station 12a. As will be observed by a comparison of these Figures with FIGS. 2A through 2E, which illustrate the surface control station circuits for the single well system 10, much of the circuitry in the two surface stations 12a, 12b is the same, the difference primarily being in the addition of circuits and components to the single well system for operation of the intermediate station 400 in the multiple well system. In addition to that already mentioned, equipment includes a second DVM 44 (FIG. 5E) connected like DVM 80 to the external 115 volt AC power supply cable 70, a BCD-to-decimal decoder driver 415 connected to the thousands BCD output of DVM 414, and another BCD-to-decimal decoder driver 416 connected to the hundreds BCD output of the DVM 414. This control station 12a also contains a power buffer 417 between the tens BCD output of the DVM 414 and each of five buffer storages 418–1, 418–2, 418–3, 418–4, and 418–5 for the five trees in the system, five BCD-to-decimal decoder drivers 420–1, etc. (only 420–1 shown) in series with the buffer storages 418–1, etc., respectively, and five SI–S2 system indicator tubes 404–1, etc. (only 404–1 shown), for the trees 1 through 5, respectively.

As shown in FIGS. 5C and 5D, the multiple well surface station 12a also includes four OR circuits 422, 424, 426 and 428 between the thousands BCD output of the DVM 80 and the decoder driver 84 to allow data to flow only to the tree display panel whose tree is being monitored. This station further includes a buffer storage 430 in series between the hundreds BCD output of the DVM 80 and the power buffer 156, and another buffer storage 432 in series between the ends BCD output of the DVM 80 and power buffer 174. OR circuits 422–428 and buffer storage elements 430 and 432 of all display panels are connected to BCD-to-decimal decoder driver 416 so that the information from the tree being monitored is displayed on the proper panel. The displays of the trees not being monitored are held in the position corresponding to the last data they received. The output of BCD-to-decimal decoder driver 416 is also connected to each of the tree identification lights 402 to illuminate the corresponding lights of the tree being monitored. OR circuits 422, 424, 426, 428, buffer storage 430, and buffer storage 432 are connected to BCD-to-decimal decoder driver 416 so that the signals from the thousands, hundreds and tens BCD's of the DVM 80 will be directed to the display panel of that tree being monitored. An additional power supply, i.e., No. 6, is included in this system for providing a constant current to the pushbutton switches 406, 408, and 560, which switches are functionally interconnected with conductor lines 434, 436 coming from DVM 414 and going to the intermediate station and cable 18a.

The relay circuitry in FIG. 5B consisting of relays 270, 280, 282, 284, 286 with their associated contacts and switches 52, 54, single-step or auto-step the individual tree connected to lines 252, 254 through the intermediate station. Their action is similar to that of the corresponding components in the single well system. One additional component is contact 284b in FIG. 5E which locks up DVM No. 2 during stepping, similar to contact 284a locking up DVM No. 1 during stepping. Within the unit 570 containing switches 406, 408 and 560 are an identical set of relays to perform the same function of stepping the intermediate tree and locking up DVM No. 1 and No. 2 during this stepping process. Therefore, there is a second 284a contact and a second 284b contact associated with the 284 relay in unit 570, both 284a contacts wired in parallel and both 284b contacts wired in parallel.

The circuit of the intermediate station 400 is shown in schematic form in FIG. 6. As is apparent from this Figure, the intermediate station broadly comprises a stepping module 500 comprising a pair of four-deck stepping switches 502, 504, the two switches providing a redundant or backup system similar to that provided at the individual subsea stations. Although FIG. 6 illustrates an intermediate station with stepping switch positions and related components for operational connection to five subsea stations, it should be understood that the number of subsea stations controllable through one intermediate station can be greatly increased, as well as reduced, merely by increasing or reducing the quantity of the switching positions and components. The intermediate station functions to lock the system - system 2 mode of the individual subsea stations, to switch to the desired Christmas tree for operating a valve or reading a valve position or pressure indication by an analog function, and to read-out the position of the switching module 500 and the condition of relays 508 through 516.

Each of the decks 502a, 502b, 502c and 502d of the stepping switch 502 is connected in parallel to the corresponding deck of the stepping switch 504, as are the decks 302a and 302b to 304a and 304b of the subsea station stepping switches 302, 304, thereby providing the same type of redundant or backup system as present in the subsea station. The intermediate station can be switched to function on either of the two systems in the same manner that switching from one system to another at the subsea station can be accomplished so that if a malfunction occurs at the intermediate station in one of the systems, the other system can be employed to carry out the needed function. Switching the system
mode of the intermediate station is accomplished by operation of the system change switch 410 to reverse the polarity of the 115 volt direct current in conductor lines 272, 274, actuating relay 506 and thereby maintaining the polarity in conductor lines 272a, 274a by closing the normally open and opening the normally closed contacts 506-1 and 506-2. The similar action of the other contacts of relay 506 switch the operation from the normal to the redundant stepping switch.

The decks 502a and 504a of the stepping switches 502, 504 are utilized to switch the mode of the subsea station from system 1 to system 2 and vice versa. The first five contact positions of the decks 502a, 504a are connected to one coil of magnetically latched relays 508, 510, 512 and 516, each relay contact being in series with the conductor lines 272a, 274a, between the intermediate station functions and the subsea station of the Christmas trees 1 through 5, respectively. Likewise, contact positions 6 through 10 of the stepping switch decks 502a, 504a are sequentially connected to the other coil of these magnetically latched relays 508 through 516. Thus, when the tree system actuate switch 560 is pressed to complete the circuit between the power supply No. 2 at the surface station and relay 572 in FIG. 6, relay contact 572a closes and actuates, with 115 volts DC from line 274a, the relay coil connected to the contact position on which the switch is resting, and the relay becomes magnetically latched in that position. With the stepping switch in position 1, relay 508 would be energized setting contacts 508a which will set tree number 1 in the S1 position. In position 6, energizing the second coil of relay 508 in the same manner will magnetically latch the relay in the opposite position which reverses the action of contacts 508a and sets tree number 1 in the S2 position.

The decks 502b, 502c, 504b, 504c of the stepping switches 502, 504 function to switch the lines 252, 254 from one tree subsea station to another, and for that purpose are interconnected in these lines such that the first five contact positions of the stepping switches are connected in sequence to the trees 1 through 5, and the 6th through the 10th contact positions are likewise sequentially connected to the trees 1 through 5. This connects the 15 volt power supply No. 2 and the DVM No. 1 to the selected tree allowing the tree to be stepped or actuated and allowing data from the tree to reach the DVM No. 1.

The decks 502d and 504d of the stepping switches 502, 504 function with the decks 502a, 504a to indicate which system mode the subsea stations are functioning in at a given time. The decks 502d, 504d are connected in parallel to the conductor line 436, their first five contact positions are connected sequentially to one set of contacts of the relays 508 through 516, respectively, and their second five contact positions are connected sequentially to another set of contacts of these same relays. Unique resistors 520R, 522R, 524R, 526R, 528R, 530R, 532R, 534R, 536R, and 538R are connected to the contact positions 1 through 10, respectively, of the decks 502d, 504d, and in series with each of these resistors are connected two more unique resistors 540R, 542R that in turn are connected to the line 434.

One set of contacts 508b, 510b, 512b, 514b, and 516b of the relays 508 through 516 are connected in parallel with the resistors 540R, a different relay with each resistor, and the other set of contacts 508c, 510c, 512c, 514c, and 516c of these relays are likewise connected in parallel to the five resistors 542R. The first five contact positions of the decks 502d, 504d are connected to the resistors 520R through 528R and corresponding deck contact positions 6 through 10 through the resistors 530R through 538R, thereby providing a unique resistance reading in the line 434 through the decks 502d, 504d for each of the ten contact positions, as well as for each of the two system modes in which the subsea stations can exist.

Although the invention contemplates the use of any resistance that in combination will provide a discernable and readable distinction between the trees and the system modes, the resistance value set forth in the following Table III has been found very satisfactory for this purpose.

The relays 572, 574, 576 and 578 in the intermediate station 400 function similarly to the relays 310, 312, 328 and 330 in the subsea station 14, allowing either an actuate or a step at the intermediate station.

| TABLE III |
|-------|------|
| Resistor | Ohms |
| 520R | 1100 |
| 522R | 1200 |
| 524R | 1300 |
| 526R | 1400 |
| 528R | 1500 |
| 530R | 2100 |
| 532R | 2200 |
| 534R | 2300 |
| 536R | 2400 |
| 538R | 2500 |
| 540R | 25 |
| 542R | 75 |

Using resistors with values as indicated in the above Table III, the following Table IV indicates the resistance ranges and system modes in all combinations.

<p>| TABLE IV |
|-------|------|------|------|</p>
<table>
<thead>
<tr>
<th>Intermediate Station Stepping Switch Position</th>
<th>Individual Tree Function (Can Switch Tree to S1 or S2- Thousands Digit)</th>
<th>Tree Displayed (Hundreds Digit)</th>
<th>Tree Function Displayed (Tens Digit)</th>
<th>Resistance Range (Ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1</td>
<td>1</td>
<td>S1</td>
<td>1100-1149</td>
</tr>
<tr>
<td>1</td>
<td>S1</td>
<td>1</td>
<td>S2</td>
<td>1150-1199</td>
</tr>
<tr>
<td>2</td>
<td>S1</td>
<td>1</td>
<td>S2</td>
<td>1200-1249</td>
</tr>
<tr>
<td>3</td>
<td>S1</td>
<td>2</td>
<td>S2</td>
<td>1250-1299</td>
</tr>
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<td>4</td>
<td>S1</td>
<td>3</td>
<td>S2</td>
<td>1300-1349</td>
</tr>
<tr>
<td>5</td>
<td>S1</td>
<td>3</td>
<td>S2</td>
<td>1350-1399</td>
</tr>
<tr>
<td>6</td>
<td>S1</td>
<td>4</td>
<td>S1</td>
<td>1400-1449</td>
</tr>
</tbody>
</table>
TABLE IV—Continued

<table>
<thead>
<tr>
<th>Intermediate Stepping Switch Position</th>
<th>Individual Tree Function (Can Switch Tree to S1 or S2; Thousands Digit)</th>
<th>Tree Displayed (Hundreds Digit)</th>
<th>Tree Function Displayed (Tens Digit)</th>
<th>Resistance Range (Ohms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>S1</td>
<td>4</td>
<td>S2</td>
<td>1450–1499</td>
</tr>
<tr>
<td>5</td>
<td>S1</td>
<td>5</td>
<td>S1</td>
<td>1500–1549</td>
</tr>
<tr>
<td>6</td>
<td>S1</td>
<td>6</td>
<td>S2</td>
<td>1550–1599</td>
</tr>
<tr>
<td>7</td>
<td>S2</td>
<td>7</td>
<td>S1</td>
<td>2100–2149</td>
</tr>
<tr>
<td>8</td>
<td>S2</td>
<td>8</td>
<td>S2</td>
<td>2150–2199</td>
</tr>
<tr>
<td>9</td>
<td>S2</td>
<td>9</td>
<td>S1</td>
<td>2200–2249</td>
</tr>
<tr>
<td>10</td>
<td>S2</td>
<td>10</td>
<td>S2</td>
<td>2250–2299</td>
</tr>
</tbody>
</table>

The bank of resistors 580–IR (FIG. 5E) between the BCD-to-decimal decoder driver 420–1 and the S1–S2 indicator tube 404–1 function in the same manner as resistors R1–R9 (FIG. 2E) between BCD-to-decimal decoder driver 206 and valve indicator tube 46, i.e., they cooperate with the circuits in the intermediate station 400 to indicate on which system the tree No. 1 presently is functioning. These resistors 580–IR are all equal in value, such as 1000 ohms or any other value suitable to the efficient operation of the circuits.

Where, as in the foregoing described embodiments of the invention, hydraulic powered Christmas tree valves, etc., are being controlled, the hydraulic pressure can be supplied through a line (not shown) that may go directly to the subsea station or stations, or it may go first to an accumulator (not shown) near the well and from there to the station. The solenoid valves 350 (FIG. 3) preferably are located in the subsea stations, together with all of the other components of the illustrated subcircuits for the valves V1–V9 except for the limit switches 372, 374, and of course the valve V1, etc., itself. Therefore, the cable 20 contains only three wires, one to each of the switches 372, 374, and the third to a line common to the contacts of both switches. Of course, where the valves, etc., are operated by pneumatic power, the same arrangement is preferred.

When hydraulic or pneumatic power is relied on for operating the valves, chokes, and other mechanisms that can be controlled by the system of this invention, these valves, etc. can be provided with means such as vents in the hydraulic or pneumatic lines causing them to automatically close when the solenoid valves 350 close. Thus, should the control system become malfunctioning, for example as a result of loss of its external power source, the solenoid valves 350 will shut off the hydraulic or pneumatic power to the valves V1–V9, thereby providing a "fail-safe" feature. If the valves V1–V9, etc., are operated by means of electric power such that when that power is removed the valve will close, for example if solenoid valves are used for V1–V9, then of course the control system could be modified by the use of relays, etc. instead of solenoid valves 350 to shut off the power to valves V1–V9.

Another of the many advantages of the system of this invention is that there is no problem of maintaining synchronization between the stepping switches at the subsea station and intermediate station with a stepping switch at the surface station, for there is no stepping switch at the surface station. The problems of this type are well known, and all of them are effectively eliminated by the unique combination of components employed in this invention.

As will readily be appreciated, the control systems of this invention are not limited in use to valves, chokes, etc. at oil, gas, or other fluid wells, but instead can be employed to control the operation of any mechanism that is powered by hydraulic, pneumatic or electric forces. Furthermore, the mechanism of course do not have to be at a subsea location, nor do they have to be remotely located with respect to the control station. In other words, the invention contemplates a wide range of applications, both surface and submerged in location.

Although the best mode contemplated for carrying out the present invention has been herein shown and described, it will be apparent that modification and variation may be made without departing from what is regarded to be the subject matter of the invention.

What is claimed is:

1. In a fluid well flow control apparatus having a system for remotely controlling the operation of electrically energized mechanisms wherein said mechanisms have a plurality of operational states, and for measuring and reading out the operational state of each of said mechanisms, said system including a control station connectable to a source of electrical power, electrical circuit means at said control station with display means having indicators for individually selectively indicating the operational state of said mechanisms, a switching station in the vicinity of the fluid well, first means including electric conductors for electrically interconnecting the control station and the switching station, and second means including electric conductors for individually electrically interconnecting the switching station with each of said electrically energized mechanisms, the improvement comprising:

a. said selective indication means having a corresponding selective response to each one of a plurality of differing predetermined voltages present in one of said electric conductors,
b. a plurality of resistors interconnected with said mechanisms for providing said differing predetermined voltages,
c. means for selectively interconnecting said resistors in response to control of said mechanisms to produce said predetermined voltages on said conductor, and wherein,
d. said plurality of resistors include first, second and third resistors, wherein said first and third resistors are selectively connected in parallel by said selective interconnecting means to provide a predetermined voltage indicating a first limit of operation of said mechanism, said second and third resistors are selectively connected in parallel by said selective interconnecting means to provide a differing predetermined voltage indicating a second limit of operation, and said third resistor alone provides a further differing predetermined voltage indicating a third state of operation when said first and second resistors are disconnected therefrom, thereby to effect display at said control station of the particular operational state of the well control mechanisms with a minimum of conductors interconnecting said mechanisms and said control station.

2. A system according to claim 1 wherein each indicator includes indicia for indicating three operational positions of the mechanism to which it is related, including the opposite limits of operation and a state of operation in between said limits.

3. The improved system of claim 1 wherein said controlled mechanisms include valves, and wherein said states of operation thereof comprise respectively: valve open, valve closed, and valve intermediate position.

4. The improved system of claim 3 wherein said states of operation of said well control apparatus further include temperature and pressure parameters.

5. A system according to claim 1 wherein said mechanism includes first and second limit switches, and wherein said first resistor is in series with said first limit switch, said second resistor is in series with said second limit switch, and said third resistor is connected across the series combination of said first and second limit switches, and their respective resistors, whereby when the mechanism is somewhere in between its limits of operation neither limit switch is closed and said third resistor only can then be measured externally.

6. A system according to claim 1, including a further plurality of resistors and at least one transducer means for measuring temperature or pressure at said well control apparatus, such that said display means indicates the measured temperature or pressure in response to specific voltages conducted from said measuring means to said display means.

7. A system according to claim 1 wherein said electrically energized mechanisms are valves, and wherein said well flow control apparatus is an underwater Christmas tree, including the further improvement wherein said first interconnecting means comprises a four-conductor electrical cable between the control station and the switching station, wherein said second interconnecting means comprises a three-conductor electrical cable between the switching station and each valve, and wherein said switching station includes means to switch from one valve to another upon command from the control station.

8. A system according to claim 1, including a plurality of separate fluid well flow control apparatuses each having its own switching station, and an intermediate station between the control station and said switching stations, the further improvement wherein the first interconnecting means comprises a six-conductor cable between the control and intermediate stations, and a four-conductor cable between the intermediate station and the switching stations, and wherein the second interconnecting means comprises a three-conductor cable between the switching stations and their related well flow control apparatuses.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,865,142
DATED : February 11, 1975
INVENTOR(S) : ROBERT A. BEGUN ET AL

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

Column 1, line 32: change "appeal" to -- appeal --.
Column 3, line 8: change "syslems" to -- systems --.
Column 4, line 33: change "Nixie" to -- Nixie --.
Column 13, line 7: change "digit" to -- digits --.
Column 15, line 57: after "units" insert -- digit --.
Column 17, line 15: change "24-1" to -- No. 1 --.
Column 20, line 5: change "533R" to -- 532R --.
Column 22, line 30: change "mechanism" to -- mechanisms --.

Signed and Sealed this thirtieth Day of March 1976

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks