SUCCESSFUL INSTALLATION OF FULL-SCALE DISTRIBUTED PROCESSING SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM AT TWO WEST TEXAS WATERFLOOD UNITS

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ABSTRACT

TEXACO U.S.A. has successfully installed an automation system which provides distributed remote control and monitoring of the entire array of producing operations at the Wharton and Robertson Waterflood Units in Gaines County, Texas. A preliminary economic analysis of the project indicates that the benefits attained have exceeded expectations.

Microprocessor based Remote Terminal Units (RTU's) are used to detect and report alarm conditions and operating data to a Master Terminal Unit (MTU) located in a field office on the Wharton Unit. RTU's have been developed to provide the following functions:

1.) Control beam pumped wells.

2.) Monitor variable speed driven electric submersible pumped wells.

3.) Monitor and control individual injection wells.

4.) Perform automatic well testing and monitor the operation of the production satellites.

5.) Monitor the operations at the tank batteries.

6.) Monitor and control the water injection plants.

The system utilizes the concept of distributed processing. That is, each Remote Terminal Unit is a self-reliant microprocessor. Malfunction or shutdown of the Master Terminal Unit does not affect the operations of the individual RTU's. To our knowledge, this is the first automation system where the concept of distributed processing has been applied to all aspects of a producing field's operation.

THE WHARTON AND ROBERTSON UNITS are adjacent waterfloods in the Harris and Robertson, North Fields in Gaines County, Texas (Fig.1). Production from the Units is from a common Permian age Glorieta reservoir. The average depth of the reservoir is 5900 feet, and typical pay thickness is 150 feet. The oil produced is a 30° API sour crude with a gas-oil ratio of 160 cubic feet per barrel.

The Units consist of a total of 5200 unitized acres. Current oil production from the two Units totals 10,900 barrels per day from 156 producing wells. Of the 109 producing wells on the Wharton Unit, 41 are beam pumped, 61 are produced with electric submersible pumps, and seven are hydraulically pumped. On the Robertson Unit, all 47 producing wells are beam pumped. Production from the wells is routed to one of eleven well test/production satellites, and on to one of three consolidated tank batteries.

Current water injection totals 32,900 barrels per day into 69 injection wells. The injection rate per well averages 525 barrels per day. The injection pressures range from 680 psi to 1850 psi. Injection pressures are limited to the reservoir fracture pressure at each well. The Wharton and Robertson Units each have a single water injection plant. Water is pumped from each injection plant to one of ten injection headers, and on to the individual injection wells.

The Units are surrounded by 15 small primary leases within a 12 mile radius. The automation of some operations on each of these leases is currently in progress.

THE SCADA SYSTEM developed for the Wharton and Robertson Units is represented in block diagram form in Figure 2. The system utilizes the concept of distributed processing. The operation of each Remote Terminal Unit (RTU) is completely independent of the Master Terminal Unit (MTU) and other RTU's. Centralized Computer Control of some functions, such as automatic well testing and beam pump control has been used by Texaco and other operators in the past, but to our knowledge this is the first project where the concept of distributed processing has been applied to all aspects of a producing field's operation.

RTU's are currently in service at each tank battery, water injection plant, well test/production satellite, beam pumped well, submersibly pumped well, and injection well.

THE MASTER TERMINAL UNIT SOFTWARE was developed for this project by Texaco's Computer Information and Services Department. In mid-1982, during the early stages of the project design, a "turnkey" vendor for the entire system was sought. The project team felt that if one vendor could supply the required MTU, RTU's, and all associated software, a thoroughly compatible system could be easily attained. However, as the project developed, it became apparent that no one vendor could supply all of the desired RTU types, and that the project team could not exercise sufficient control over the MTU software development if it were contracted out. Development of the software in-house resulted in a system that was flexible enough to easily be used in other fields, and "user friendly" enough that a production foreman with no previous computer experience can operate the system with no local programmer support. Further advantages of in-house development of the MTU software include long term support of the software and substantially reduced costs for future automation projects.

The distribution of the system's intelligence from the central computer to the lower RTU level has left the MTU with five major functions: alarm processor, repository of historical data, report generator, operator interface to the individual RTU's, and communications controller.

The individual RTU's detect and report alarm conditions to the Master Terminal Unit located in a field office on the Wharton Unit. Each RTU is scanned every fifteen minutes for alarm conditions and changes in status. The MTU assigns the alarm an operator defined priority, time tags it, and sends an appropriate message to an alarm printer. Only changes in status points are processed as alarms, therefore each alarm is printed only once. When an RTU senses an alarm condition, two status bits are set. The first, or current status, indicates that an the condition currently exists, while the second, or latched status, indicates that the condition has occurred. This enables the MTU to process and report alarms which have occurred and cleared between the fifteen minute scans.

In addition to the fifteen minute status scans, the MTU performs data scans of every RTU every hour. During this scan, operator selected data points are retrieved and logged into historical data files. Hourly, daily, monthly, or lifetime data can be plotted or tabulated by the operator. Also, well file type information, including a summary of all well equipment, well bore diagrams, and well history is kept for each well.

On a scheduled or demand basis, the Master Terminal Unit generates morning, monthly or demand reports and summaries. Immediately after the 7:00 AM data scan, the thousands of pieces of data collected throughout the previous 24 hours are organized and presented in a meaningful manner in the Morning Report. In a similar manner, a Monthly Report is generated at the conclusion of every month that summarizes and condenses important information contained in the Morning Reports.

The MTU also has the ability to poll any RTU at any time for detailed information and to input or alter operating parameters. Demand scans can be run on individual RTU's, or summaries can be run on some or all RTU's of a particular type. For instance, the current operating status of all beam pumped wells on the Wharton Unit can be retrieved on demand. Also, current operating conditions at certain RTU's can be viewed in a schematic form. For instance, a schematic of the tank batteries can be viewed on demand. The schematic is a representation of the facility which graphically shows such information as current tank levels, status and alarm conditions, and current rates and pressures.

The role of the MTU as communications controller will be discussed in a future section.

THE MTU HARDWARE is based on two Data General MV 4000 computers. The two MTU's are identical and operate completely independently of each other. One computer serves the Wharton Unit only, while the second serves the Robertson Unit and all outlying primary leases.

Each MTU consists of: the MV 4000 computer, a 356 megabyte Winchester disc drive for program and data storage, a magnetic tape drive for running backup tapes and archival storage, four 19 inch high resolution color graphics CRT's, four black and white CRT's, a hardcopy command console, one report printer, and one alarm printer. A dual four ton air conditioner was required to cool the computer room of the field office.

The computers are not connected to any other Texaco computers. The system was intended for use as a field production tool, and is therefore not linked to a company mainframe.

THE BEAM PUMPED WELLS are controlled and monitored by Model 700CS Beam Pump Controllers, produced by End Devices Inc. of Midland, Texas. The operation of this RTU is diagrammed in Figure 3.

The pump off controller consists of three major components: a strain gauge welded to the walking beam, a magnetic type proximity switch, and a microprocessor. The strain on the beam, as measured by the strain gauge, is proportional to the load on the polished rod. The proximity switch is used to sense a single point in the stroke. As the counterweight pass by the switch, it closes momentarily. This switch closure is used by the microprocessor to synthesize a position signal for the entire stroke. Using the signals from the proximity switch and the strain gauge, the microprocessor internally generates a dynagraph of every stroke.

A dynagraph is essentially a plot of rod load versus position in the stroke. When there is sufficient fluid in the wellbore to allow for complete pump fillage, the dynagraph repeats itself stroke after stroke. However, when the fluid level has been pumped down to a point where the hydrostatic head of the annular fluid is insufficient to provide complete pump fillage, the rods retain the fluid load through part of the downstroke. The area under the downstroke portion of the dynagraph therefore increases.

The pump off controller integrates the area under an operator defined portion of the dynagraph. When the area exceeds a user defined setpoint, the pumping unit motor is shut off for a predetermined amount of time. This scheduled off time is determined by the operator, and varies from well to well, depending on a particular well's inflow characteristics.

The Pump off controller is mounted on a pole near the pumping unit. Data in the controller can be viewed and modified locally with a portable Operator Entry Unit, or at the MTU via communications through a modem. In addition, stored and current dynagraphs can retrieved, viewed and saved at the MTU. The dynagraphs viewed on the color graphics CRT at the MTU show the date and time that the dynagraph was saved, peak and minimum polished rod loads, and calculated polished rod horsepower and kilowatt demand.

The pump off controllers accept and accumulate inputs from pulse initiating kilowatt-hour meters. These KWH meters have been installed on each beam pumped well in the project. Energy consumption for each well is reported to the MTU hourly, where it can be plotted or tabulated. This information has facilitated accurate testing of new equipment used in beam pumping applications.

Conditions at the beam pumped wells which generate alarms at the MTU include: polished rod load changes which could indicate a rod part, large deviations in percent run time, 24 hour runs, high and low KWH consumption, loss of load or position signal which result in the controller defaulting to a percentage timer, or communication system failure.

THE ELECTRIC SUBMERSIBLE PUMPED WELLS on the Wharton Unit are all equipped with microprocessor based variable speed drives. These drives accept an input from a bottom hole pressure sensor, and increase or decrease the motor frequency to maintain a constant bottom hole pressure. Since the wells are controlled by the variable speed drives, the RTU's developed for the ESP's are used only to monitor, not control, the wells. There are two brands of drives in use on the Wharton Unit wells, produced either by Electric Machinery Industrial Controls Corporation (EMICC), or Centralift-Hughs. Based on the type of variable speed drive in use, two different RTU's were developed for monitoring the ESP wells. For the EMICC panels, RTU's were developed by Teledyne Geotech, of Garland, Texas. RTU's built by End Devices, Inc. are used on the Centralift drives. Both RTU's monitor essentially the same points. The ESP RTU is shown schematically in Figure 4.

The RTU's monitor: bottom hole pressure, flowline pressure, motor frequency, AC and DC amps and volts, power factor, kilowatt-hour consumption, run status, overload and underload status, cooling system status, and power fail status. The RTU's perform all limit checking, and report the appropriate alarm conditions to the MTU during the 15 minute status scan.

In addition to early detection of surface equipment failures, the data collected from the ESP RTU's has been used to detect such problems as worn and inefficient pumps, paraffin buildup in the tubing and flowlines, and changing well inflow characteristics.

INJECTION WELL CONTROL is accomplished at the injection headers utilizing RTU's developed for Texaco by Teledyne Geotech. A schematic of the control system is shown in Figure 5. Each well's individual injection line has been equipped with a turbine meter, a manual choke, an electrically operated control valve, and a pressure transducer. Each RTU has the ability to control two injection wells.

A rate setpoint and pressure setpoint are input to the RTU via the MTU or a portable Interactive Operator Entry Unit. The RTU continually samples the injection rate and pressure from each well it controls, and adjusts the control valves so that neither setpoint is exceeded.

The RTU maintains an hourly log of operating parameters for a 24 hour period, and cumulative water injection for each well.

At any time, the RTU can be requested to suspend its normal control operations and perform tests to determine current reservoir conditions. These include a step-rate and a fall off test. The results of the step-rate and fall-off test can be viewed in a tabular or graphical form, and stored at the MTU. Fall-off tests can be plotted in either a log-log or semi-log (Miller-Dyes-Hutchison) format, or both.

Conditions at the injection wells which generate alarms at the MTU include: high and low pressure and rates, pressure transducer failure, microprocessor diagnostics failure, and AC power failure.

THE WELL TEST/PRODUCTION SATELLITES on the Wharton and Robertson Units are monitored and controlled by RTU's developed for Texaco by Teledyne Geotech. Figure 6 diagrams the operation of the satellite RTU's.

The satellites consist of a header with motor actuated valves on each well flowline, a three phase test separator, a three phase production separator, and a gas scrubber. Each separator is equipped with a net oil analyzer.

The net oil analyzers use readings from turbine meters and capacitance probes to calculate the volumes of oil and water produced through each separator. This data is then transmitted to the RTU.

The RTU's have three possible modes of operation: Automatic, Manual, and Off. In the Automatic mode, wells are sequentially tested for operator determined periods of time, based on a predetermined test schedule. In the Manual mode, the operator can remotely test a selected well. In the Off mode, the RTU is used only to report status and alarm conditions.

Data from a current well tests is transmitted from the RTU to the MTU every hour. At the completion of a test, the data is compared to the previous test of the same well. If the volumes of oil, water, total fluid, and percent run time are within operator defined acceptable percentages of the previous test, the data is automatically put in the "allocation test" file, and used in a production allocation program. If the test falls outside of these limits, the MTU prompts the operator to either accept the test for allocation purposes, store the test in a history file only, or delete the test.

Up to 18 well tests for each well can be stored on disc at the MTU, where they can be tabulated and plotted against time. Additional tests can be stored on tape.

Well test information and total satellite production are calculated hourly and stored in the RTU for 24 hours. In addition, daily volumes are saved for seven days and monthly volumes are saved for the previous two months. This storage of data was provided to prevent the loss of history in the event of a failure of the MTU or communication system.

Conditions at the satellites which generate alarm messages at the MTU include: high and low separator pressures, high level in the separators, high and low fluid production rates - for both oil and water, multiple wells producing into the test separator, transfer pump failure, and AC power failure.

TANK BATTERY MONITORING is also performed using a Teledyne Geotech Remote Terminal Unit. Figure 7 is a diagram of the Wharton Unit tank battery.

The operations being monitored by the tank battery RTU include: oil sales through the LACT units, oil levels in the stock tanks, free water knockout pressure, and lease total KWH consumption. Also, the RTU monitors various status points at the LACT units, vapor recovery units, emergency gas flare, hydrogen sulfide detectors, and free water knockout.

Using the data obtained from the stock tank level detectors and the LACT unit meters, the RTU calculates the volume of oil produced and sold each hour. The MTU then allocates the tank battery total oil production to the satellites, based on the sum of the total satellite production. Production is then allocated from the satellites to the individual producing wells, based on the most recent accepted well test.

Lease total oil production can be plotted or tabulated at the MTU on request.

Conditions at the tank batteries which generate alarm conditions at the MTU include: high level or pressure in the free water knockout, high concentration of hydrogen sulfide, high and low oil production rates, oil bypassing the LACT units, LACT unit meter fail, LACT unit power fail, vapor recovery unit malfunction, flare burning, flare pilot out, and AC power fail.

WATER INJECTION PLANT CONTROL in the project is performed with another RTU developed for Texaco by Teledyne Geotech. The Wharton Unit water injection plant, the most complex plant in the project, is diagrammed in Figure 8.

The Wharton unit injection plant essentially consists of a produced and a fresh water receiving tank, two fresh and one produced water suction tanks, an emergency overflow tank, two filters and a vacuum degasification tower for the fresh water, and six National J-275 horizontal quintuplex plunger pumps.

The functions performed by the water injection plant RTU's include:

1. Measure water injection rates and maintain separate cumulative volumes for fresh and produced water.

2. Monitor the status of the suction tank valves.

3. Measure fresh water input to the plant.

4. Monitor levels of the suction and emergency overflow tanks and compute the volume of produced water received from the tank battery.

5. Perform volumetric efficiency calculations for each pump.

6. Monitor the status of the vacuum tower pumps, fresh water transfer pumps, tower pressure, and differential pressure across the filters.

7. Measure the energy consumption of the plant.

8. Monitor and control the plant discharge pressure.

The plant alternates injection of fresh and produced water. Plant output is measured with a turbine meter in the plant discharge line. The RTU maintains separate volumes of fresh and produced water injected by correlating the state of the suction valve status switches with the master turbine meter reading.

The RTU also monitors the state of the valve status switches for ambiguities, such as fresh and produced water valves open simultaneously, or all valves closed.

The volume of fresh water entering the plant is also measured with a turbine meter.

The suction tank and emergency tank levels are measured with differential pressure transducers. Every hour, using tank levels and turbine meter readings, the RTU performs a material balance to calculate the volume of produced water received from the tank battery. This information is relayed to the MTU during the hourly data scan.

Turbine meters were also placed in the discharge line of each individual pump. A tachometer on each pump measures the RPM. Using the readings of the tachometers and turbine meters, the RTU calculates an efficiency for each pump hourly. Pump efficiencies can be plotted against time at the MTU.

Several status and analog inputs are monitored to determine the condition of the vacuum degasification tower. Differential pressure switches are used to determine when the inlet fresh water filter requires servicing. Status switches monitor the run status of the vacuum pumps and fresh water transfer pumps. Vacuum tower pressure is measured with an absolute pressure transducer. The overall performance of the degasification process is measured with a dissolved oxygen meter.

A pulse initiating kilowatt-hour meter is used to measure the total energy consumption of the plant.

Since the injection pumps are positive displacement type and the injection wells are controlled on rate and pressure setpoints, a method of controlling the plant discharge pressure was required. This was accomplished by installing a variable speed drive on one of the injection pumps. The RTU monitors a pressure transducer in the plant discharge line. The variable speed drive is then directed by the RTU to increase or decrease the motor frequency of one pump to maintain a constant discharge pressure. If the plant discharge pressure setpoint is unattainable after adjusting the output of the variable speed pump, the other five pumps in the plant are sequentially shut off or started until the set-point is reached. If the discharge pressure is above the setpoint after the five conventional pumps are shut off, and the variable speed pump is running at minimum RPM, the variable speed pump is killed, and no automatic restarting is attempted.

Like all RTU's in the project, the water injection plant RTU's perform their own limit checking and report the appropriate alarms to the MTU on the 15 minute status scan.

RTU-MTU COMMUNICATIONS is accomplished over both UHF radio and buried wireline transmission. RTU's within the Wharton and Robertson Units were connected to the MTU via buried cable wherever possible. In instances where surface facilities or long distances made the installation of buried cable impractical, UHF radio transmission equipment was installed. In all, nine RTU's in the Units use radio transmission. Data transmission from 42 RTU's on the outlying primary leases is by radio.

The decision to use buried cable instead of radio transmission as the primary communication medium was made for three reasons. First, the close proximity and spacial density of the RTU's on the Wharton and Robertson Units made the cable alternative less expensive than radios. Second, 25 pair buried cables running from the master station area to each satellite were already in place. These existing cables were part of an old semi-automatic well test system and had been used without problems since 1978. Finally, it was felt that faster and more reliable communications could be accomplished through hardwire.

The communication system is essentially a multidropped, polled network. Each MTU has 14 ports available for communication to RTU's. One of these ports on each MTU is dedicated to radio communications. All radio-equipped RTU's are connected to this port. Up to 21 RTU's are connected to each port dedicated to wireline transmission. Each message transmitted from the MTU contains an RTU address. All RTU's on a particular line receive each MTU transmission, but only the RTU which receives its address responds. The MTU initiates all communications.

Since the MTU software was written by Texaco, and two different contractors developed the various RTU's, a communication protocol agreeable to all parties had to be established early in the project. The protocol is essentially a nine byte, asynchronous format. Each byte contains a start bit, eight data bits, and a stop bit. The nine bytes in each message typically contain the RTU address, the requested function code (RTU memory location), the data bytes, and a cyclic redundancy check to establish the validity of each data exchange. The message may also contain a request for multiple functions, which results in "data steaming". Data streaming drastically reduces the time required to transmit a long continuous data set, such as the points which comprise a dynagraph.

The modems in use in the project vary with the RTU type and transmission medium. All modems operate in a four wire, full duplex mode, except those used in radio communications, where half duplex operation is required.

Bell 103 compatible modems are in use at the water injection well RTU's, the Teledyne Geotech submersible pump RTU's, and on all RTU's which communicate over radio. The Bell 103 modems use frequency shift keying (FSK) type modulation. Currently all Bell 103 modems in service are operating at 300 baud. Extensive line amplification and impedance balancing equipment was required on the hardwire lines dedicated to the Bell 103 modems.

Bell 202 compatible modems are used in the remaining RTU's within the Units. These are also FSK, phase coherent modems which operate in an asynchronous four wire, full duplex mode. The Bell 202 compatible modems are operating at 1200 baud with no external impedance balancing and a minimum of line amplification equipment.

Originally, bipolar pulse modulated modems were used instead of the Bell 202 modems. These modems were inexpensive, provided easy installation and required no impedance balancing equipment. There was no limit to the number of remote modems which could be multidropped on a given line. However, an incompatibility in the comm line grounding requirements at the RTU's and MTU became painfully apparent when a single electrical storm destroyed 24 modems. The bipolar pulse modems were replaced with the Bell 202 modems, and closer attention was given to transient protection equipment.

THE TRANSIENT PROTECTION SYSTEM for the wireline network utilizes of a combination of gas tube, silicon suppression and MOV (metal oxide varistor) technologies. Each modem has three inputs: AC power, comm line, and EIA connector to the RTU. Each input must be protected against transient electrical surges. In this network the AC power inputs are protected with MOV's and lightning arrestors, the EIA connections are protected with a combination of gas tubes and zener diodes, and the comm lines are protected at the modems with MOV's, gas tubes, and zener diodes. Also, each comm line junction box contains a gas tube arrestor terminal block. The cable shields are grounded at the MTU only. No modems have been been damaged by over-voltage conditions since the installation of this equipment.

A rotary uninterruptible power supply with a backup generator and isolation transformer completely isolates the Master Terminal Unit from surges in the utility company power lines.

THE PROJECT ECONOMICS used in the original justification of the project were based on modified results reported by Shell on a project installed on their Denver Unit. The anticipated benefits of Texaco's system included a four percent production increase, a 20 percent reduction in energy consumption, and a 30 percent reduction in lease maintenance costs. Although the actual results of this project were unfortunately masked by an infill drilling program which essentially doubled the number of producing wells in the Wharton and Robertson Units, the installation of certain aspects of the project resulted in benefits which clearly exceeded the expectations.

The total cost of the project, exclusive of the automation of the outlying primary leases was approximately 2.5 million dollars.

The beam pump controller installation resulted in the most significant benefits attained. A study was made of 45 beam pumped wells which were unaffected by the infill drilling program and subsequent well conversions. Data was tabulated for the operation of these wells for a period of 12 months before and after the controller installation. The results showed a 39 percent reduction in average pumping time per barrel of fluid lifted. This reduced pumping time resulted in a 32 percent reduction in energy consumption by the beam pumped wells (data obtained from kilowatt-hour meters). Reductions in maintenance costs also exceeded expectations. By essentially eliminating the occurrence of fluid pound, rod part frequency was cut from an average of 1.16 parts per well per year to 0.44 parts per well per year, for a reduction of 62 percent. Similarly, pump failures were reduced from 0.49 to 0.22 failures per well per year, for a reduction of 55 percent. Production increases resulting from the installation of the beam pump controllers were difficult to document due to operational changes which took place during the drilling program. In general, production increases due to pump-off controller installation result from correcting existing problems such as under-pumping. The wells in this project were generally over-pumped before the controller installation. No significant production increase due to the controller installation (exclusive of reduced downtime) was evident for the entire lease, however, a few wells which were being under-pumped showed substantial improvements. Production increases due to early detection and reduced frequency of rod and pump failures were evident, and amounted to 1.6 percent of the oil produced by beam pumped wells. This translates to a 90 percent decrease in the annual production loss to downtime.

The savings in reduced maintenance and energy costs, plus the increased revenue from reduced downtime resulted in an estimated total annual benefit due to automation of the 88 beam pumped wells on the Wharton and Robertson Units of $ 930,000. The total cost of the pump-off controllers and associated end devices, communication, and transient protection equipment was approximately $ 413,000.

The installation of the beam pump controllers was the first aspect of the project completed. A complete economic evaluation of the remainder of the project is still several years from completion. However, certain advantages of the remainder of the system have already become apparent.

Control of the water injection wells was clearly worthwhile. Injection at the maximum rate attainable below reservoir fracture pressure is vital to maximizing production from this rate sensitive waterflood. However, no rigorous economic analysis has been completed on this portion of the project.

Automatic well testing and satellite monitoring has streamlined lease operations and increased the reliability of well test data. However, production increases due to more accurate well tests are difficult to document.

The benefits attained from tank battery, water injection plant, and submersible pump monitoring will require several years to document.

THE FUTURE of producing field automation projects within Texaco will depend to a large extent on the final proven merits of this system. Those aspects of the system which have already proved beneficial, such as beam pump and injection well control are currently being installed in other Texaco operated fields.

REFERENCES

1. Texaco, Inc.: "Production Surveillance System - System Functional Specifications", June 15, 1983.

2. Neely, A.B.: "Shell Expands Computer Production Control", Oil and Gas Journal (March 21, 1981) 97-120.

3. Smith, M.W., Cardella, S.J., editors, "Transient Voltage Suppression Manual", fourth edition, General Electric Company, c. 1983.

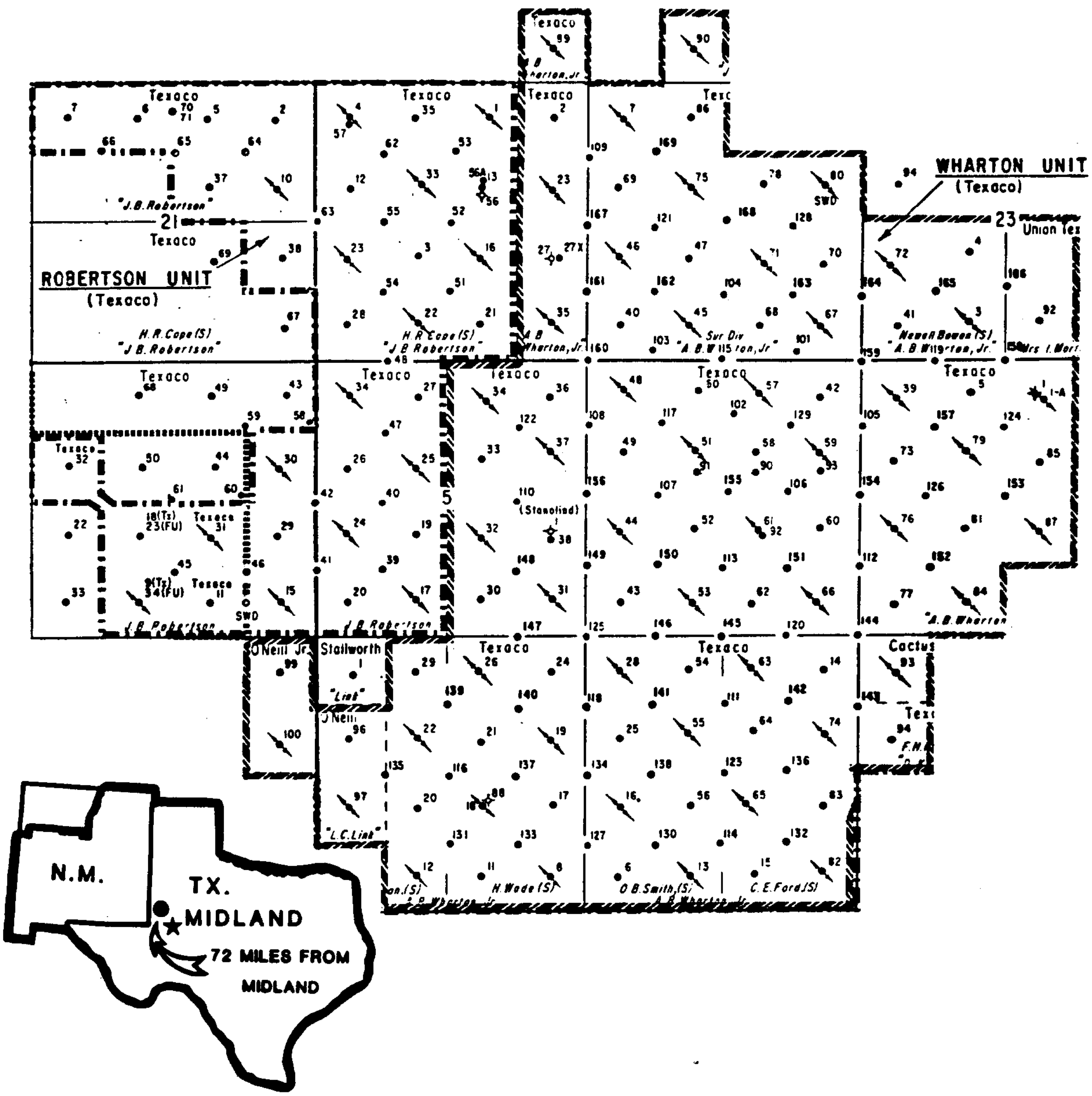


Figure 1 - Robertson and Wharton Units - Gaines County, Texas

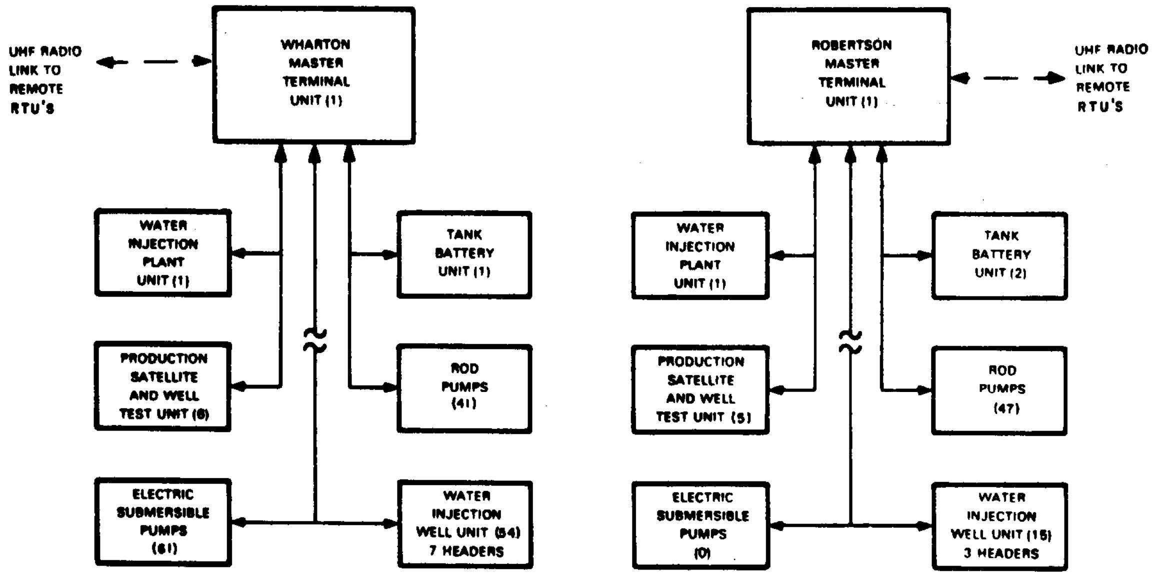


Figure 2 - Block diagram of SCADA System

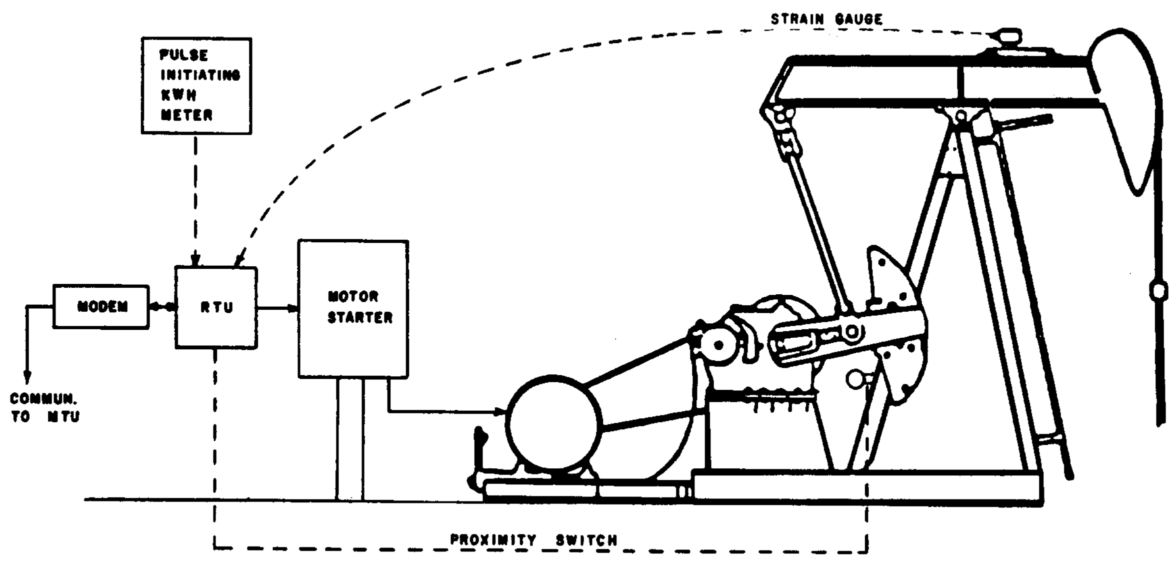


Figure 3 - Beam pumped well control.

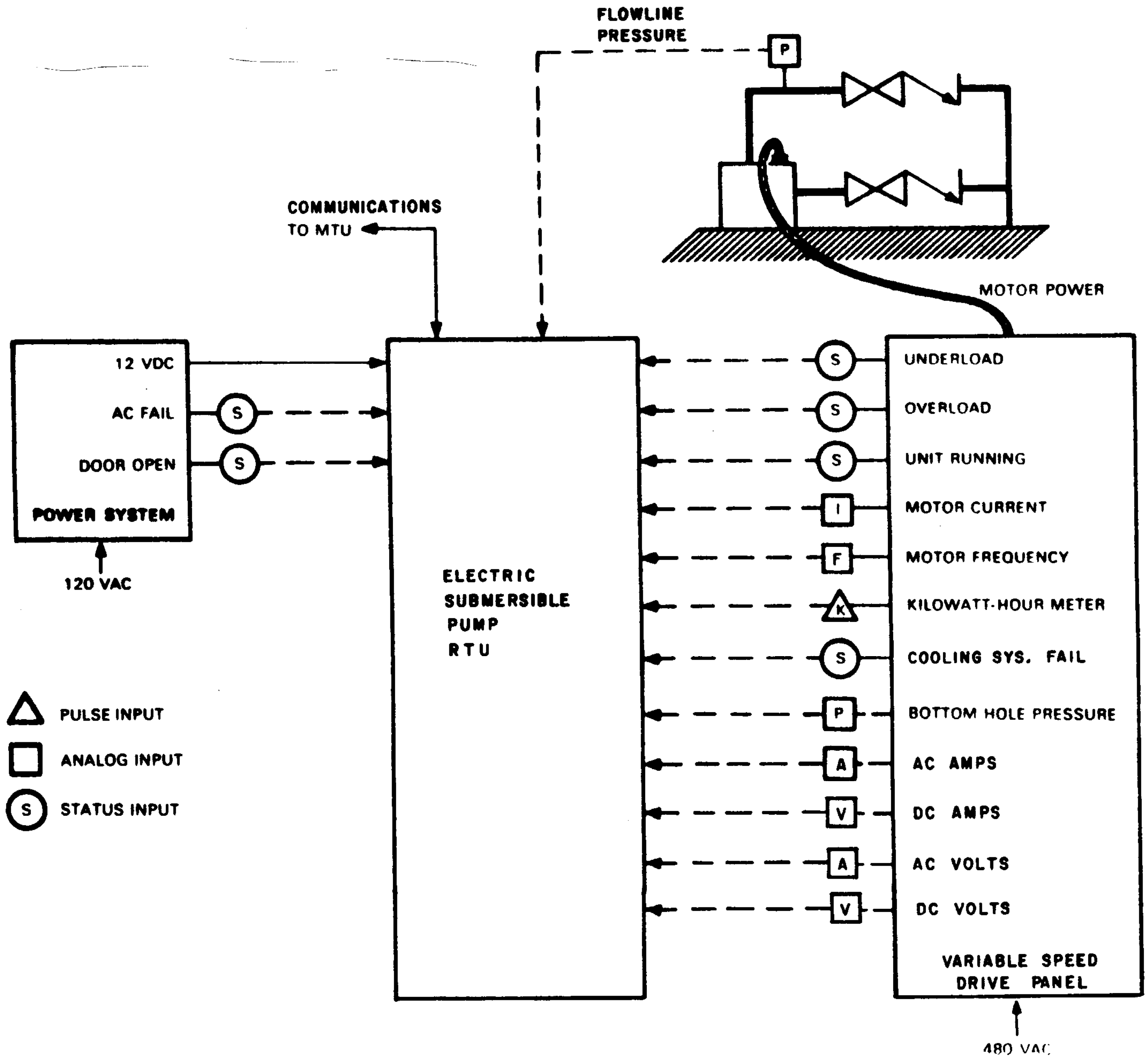
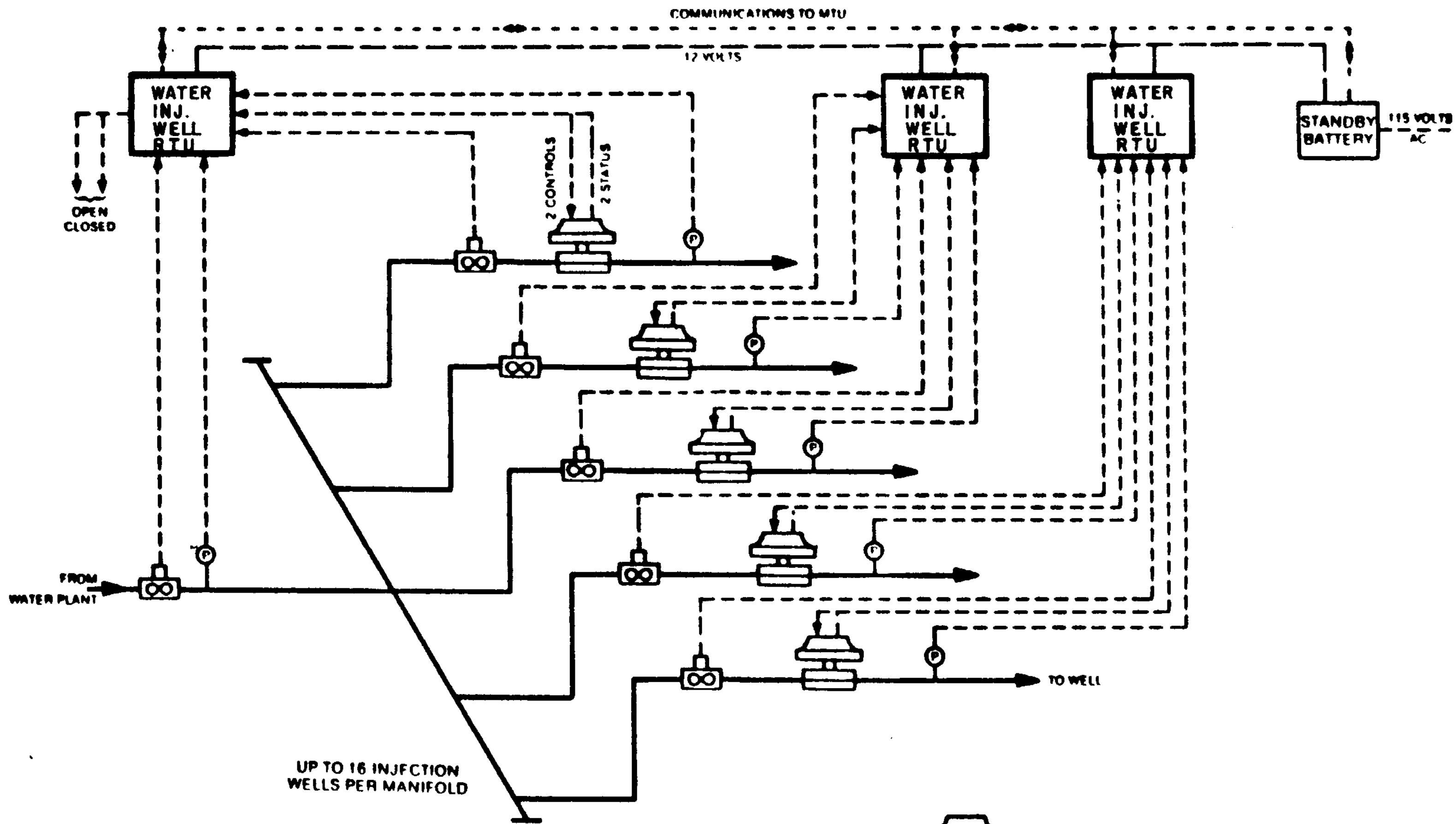


Figure 4 - Electric submersible pump installation



FUNCTION

- MONITORS TOTAL INJECTION RATES. VOLUMES
- MONITORS WATER SUPPLY PRESSURE
- CONTROLS INJECTION RATES. VOLUMES
- CONTROLS INJECTION PRESSURES
- PERFORMS STEP RATE TEST
- PERFORMS FALL-OFF PRESSURE TEST

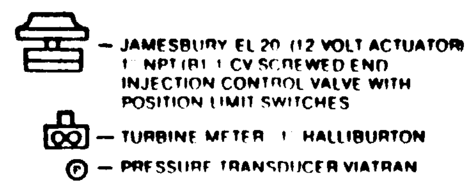


Figure 5 - Water injection well control schematic

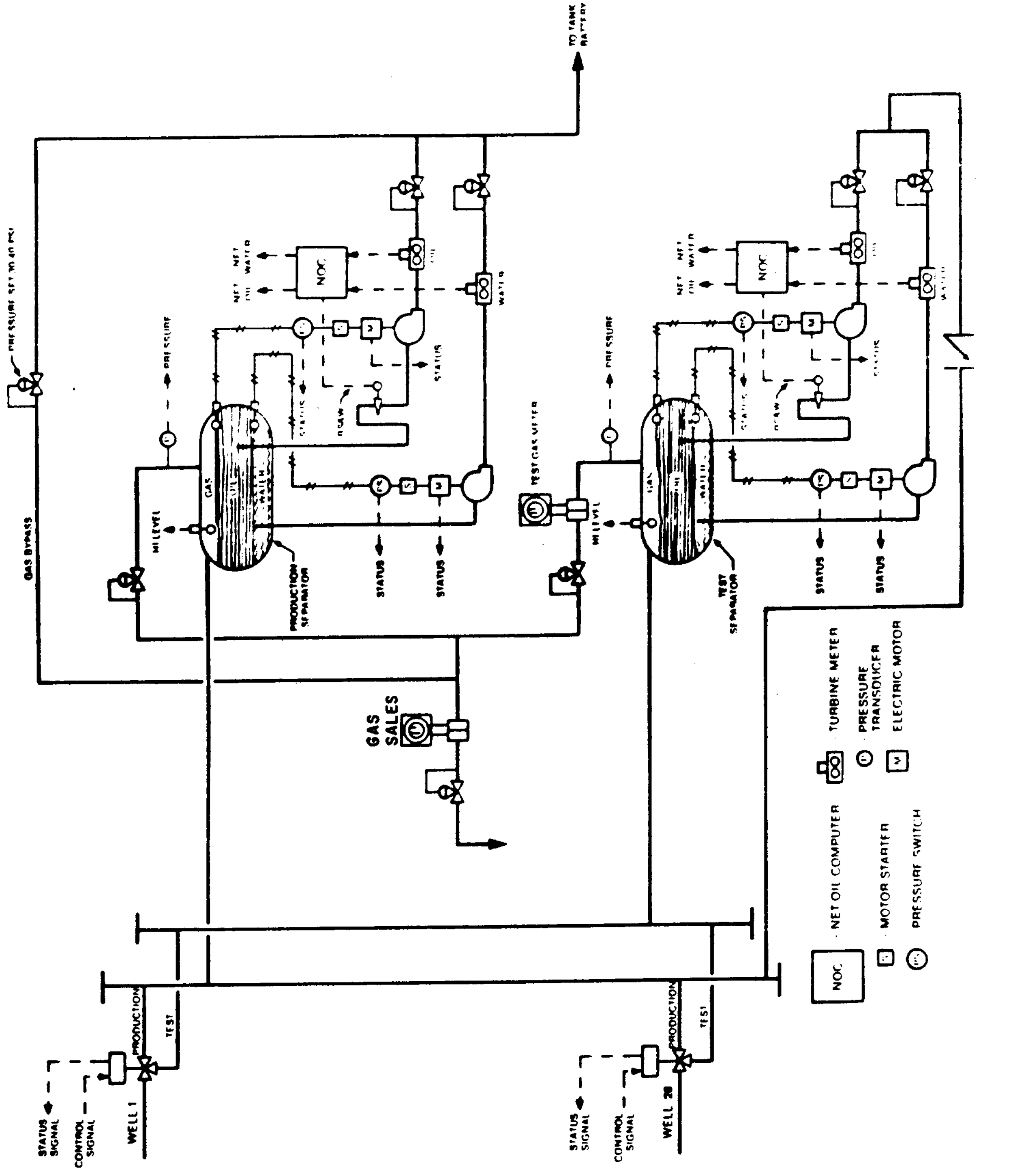


Figure 6 - Automatic well test/production satellite configuration

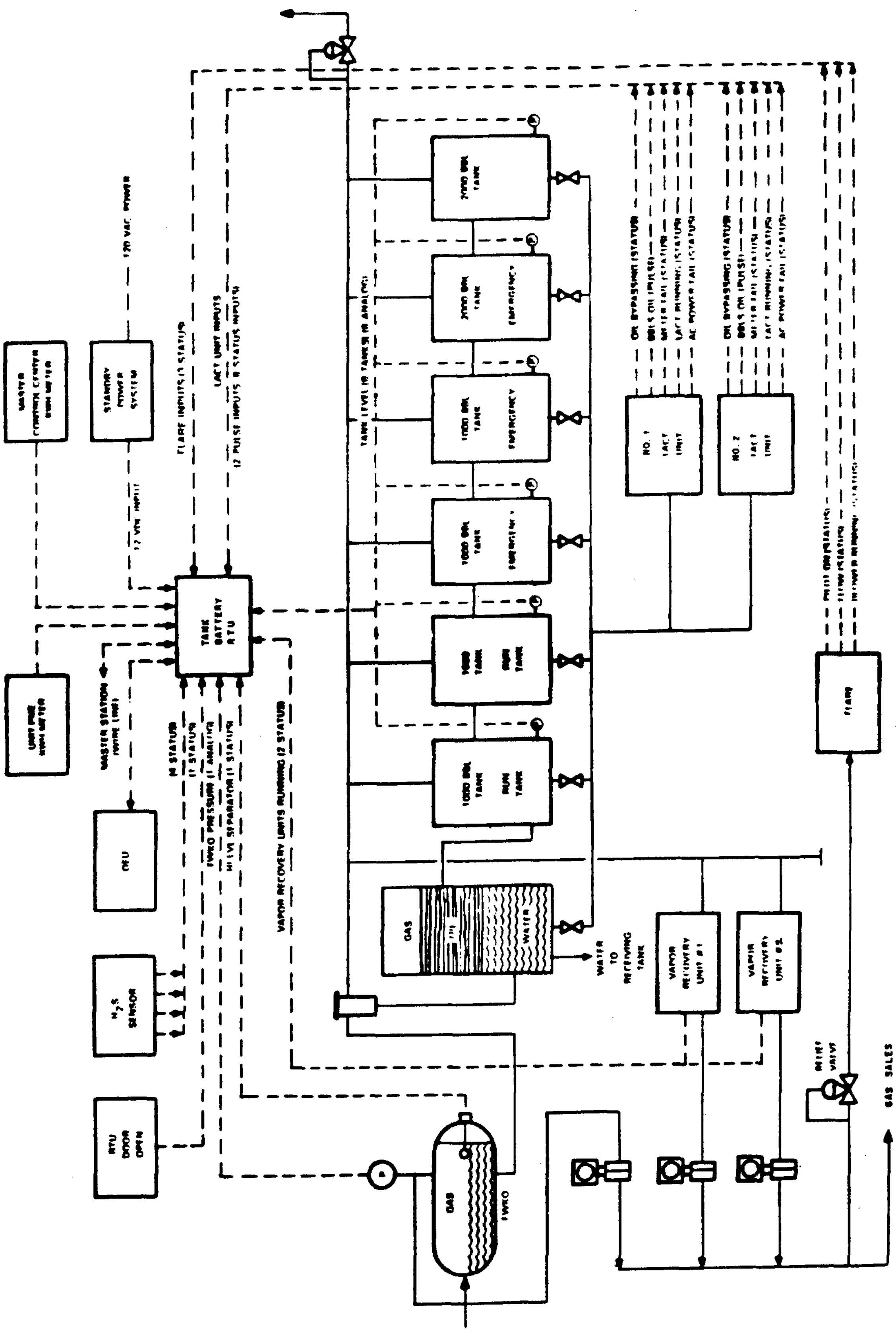


Figure 7 - Wharton tank battery unit

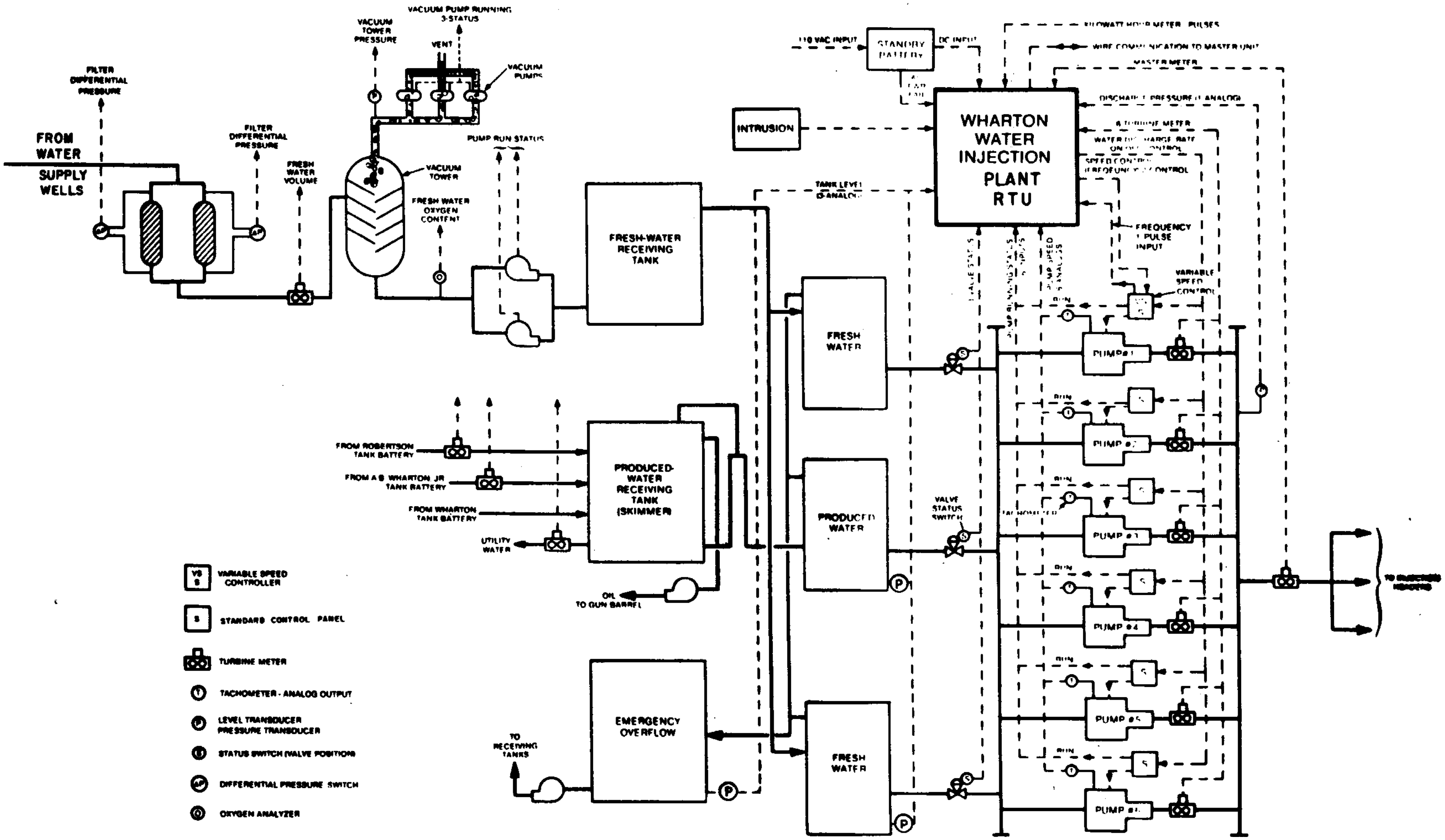


Figure 8 - Wharton unit water injection plant