CONTROL SYSTEM FOR GEOTHERMAL DISTRICT HEATING

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ABSTRACT

This report describes a study which was undertaken to determine the requirements and possible technical approach for the development of a supervisory control and data aquisition system (SCADA) for a small geothermal district heating system. For this purpose the Seltjarnarnes District Heating System is studied in some detail, the general requirements for a SCADA system are established and some of the technical aspects of its implementation are discussed in depth. The conclusions are presented in the form of a candidate system configuration based on low-cost microprocessor equipment which has become available in recent years.

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1 INTRODUCTION

1.1 Scope of work

The author of this report was awarded an UNU Fellowship to attend the UNU Geothermal Training Programme sponsored by the National Energy Authority in Iceland from April to October 1984.

During the first four weeks of the training the author received an introductory lecture course which dealt with all aspects of science and technology relating to geothermal energy.

The following weeks were devoted to special training in geothermal utilization, mainly geothermal district heating and control theory as well as computer application. This training was provided by geothermal specialists of the National Energy Authory, University of Iceland, Fjarhitun Engineering Consultants and Verk- og kerfisfraedistofan (VKS Ltd.).

A two week field excursion to many places in Iceland gave the author a good chance to visit several geothermal fields, geothermal district heating services and geothermal electric power stations. The use of heat pumps and control system in the Akureyri District Heating Service were of particular interest.

A special trip was arranged to Akureyri to get a more detailed understanding of the use of heat pumps after the field excursion. The taining was completed with a final project as presented in this report.

1.2 Objectives of training and scope of the project

The author has been engaged in the gas supply system control in Tianjin Gas Company, China, and planned to study control systems for geothermal district heating with the objective of designing a cost-effective control system for the district heating system in Tianjin upon returning to China. Because of the small scale of the distribution system in Seltjarnarnes District Heating Service, its present control system is relatively simple and needs to be improved. Therefore, the author selected to study the control problems for this system as the final project of his pratical training.

In this project the status of the district heating system in Seltjarnarnes is described. Then the basic requirements for process control and for a supervisory control and data aquisition system are presented. Finally a candidate SCADA system is described for the Seltjarnarnes district heating system.

2 THE SELTJARNARNES DISTRICT HEATING SYSTEM

2.1 General description

2.1.1 Introduction

Seltjarnarnes is a community on the northwestern tip of the Reykjavik peninsula (see Fig.2-1). It is connected to Reykjavik and is only about 3 km from the center of the capital. The population of the town is about 3700 and the total volume of the houses is $5.4\ 10^5\ m^3$.

The Seltjarnarnes District Heating System was built in 1972. At that time only about 2000 people lived there. The system was relatively small, having only 2 boreholes and the hot water supplied was about 180 m^3/hr. With the increasing number of inhabitants in this community the district heating system has been expanding gradually. Now the system serves 850 subscribers with 180-300 m^3/hr of hot water drawn from 3 geothermal wells with a fourth soon to be added (Ref. 1).

2.1.2 Geothermal wells and chemical characteristics of the fluid

Five wells have been drilled in the Seltjarnarnes area. The wells are located on the edge of the town. The depth of the boreholes varies form 856 to 2200 m, the temperature of the pumped water runs from 70°C to 116°C and the regional water level is now about 20 m. Up to 40 l/sec can be pumped from the best yielding drillhole. The chemical composition of the water is shown in Table 1 which is obtained from Ref. 2. The table shows that the content of chloride and dissolved solids is rather high and is increasing. Water with high salinity is not suitable for direct use in district heating and is also undesirable for tap water. Therefore, heat exchangers are being widely used in individual houses.

2.1.3 The system diagram

The system diagram is shown in Fig. 2-2. The hot water is drawn from boreholes by three multistage mixed flow turbine pumps driven by electric motors at the top of the well. One pump can be operated as a variable speed pump, using a variable frequency power supply unit.

The hot water is pumped into a degasser tank with a volume of 4 m3. After degassing the water is boosted in the pumping station through a short pipeline into the distribution network.

Because of the high salinity of the hot water heat exchangers are commonly used in each house to heat up the cold water for hot tap water and they are now also required for house heating. For the house connection see Fig. 2-3.

The hot water from the degasser tank is above 90°C. A mixing loop is employed in the pumping station to mix the hot water with the return water from the double pipe system. The temperature of the mixed water is about 80°C. The double pipe system extends to about 40 per cent of the users. Other users are supplied by a single pipeline system, in which used water is released into the sewer.

The maximum flowrate method is used for metering. The flow fluctuations in the Seltjarnarnes district heating system are therefore smaller than in Reykjavik where the total flow metering method is used.

2.2 Original control system design

2.2.1 Introduction

There were four control loops installed in the original system (Fig. 2-4):

a) water level control for the degasser tank; b) pressure control for the water supply; c) temperature control for the supply water; d) control of the return water pressure.

All the control valves were operated pneumatically. The deep well pumps were controlled manually.

2.2.2 Water level control for degasser tank

The water level in the degasser tank is controlled by throttling the flow from the wells based on the difference between the setpoint and actual level in the tank. The opening of the control valve is adjusted frequently with the variation of the system water demand and some energy is lost over the valve. This loop is still in operation.

2.2.3 Pressure control for water supply

The supply pressure is controlled by a pneumatic valve V2 (see Fig. 2-4) based on the differential pressure at certain points in the distribution network. The delivered pressure is adjusted over a range of 4.0-4.5 bar which is the design pressure of the network.

2.2.4 Temperature control of the supply water

The hot water and return water are mixed in front of the suction side of the boost pump. The temperature of the mixed water is measured at the discharge side of the pump and fed back to the temperature controller. The opening of valve 3 is depended on the error signal (difference between the setpoint of the controller and actual temperature of the mixed water). If the temperature increases V3 is opened and more return water is allowed to mix with the hot water, causing the temperature to decrease. If the temperature goes down,the opposite happens. This control loop is no longer operational.

2.2.5 Control of return water pressure

V4 is used to keep the return water pressure in the double pipe system at about 1 bar. When the pressure is higher than that, the extra water will be drained into the sewage system through control valve V4.

2.3 Present control system

The present control system is in fact simpler than presented above. Most of the control units have been taken out of use except the water level control for the degasser tank which is still being used. The reason for this is apparently that the control valves performed badly and had a tendency to assume on/off positions.

A variable frequency power supply unit was introduced into the well pumping system. The speed of the well pump is manually controlled according to the water demand of the network.

2.4 Basic requirements for process control

2.4.1 General description

The role of the monitoring and control system for public utilities such as district heating systems is most significant because the system serves the general public. If the system breaks down for a long time the consequences can be serious. In some sense the users play a part of the system operator function, although they are not familiar with the system process. Thus the user's operation is a disturbance to the system. Safety and reliability are the main factors to be considered, in addition to maintaining the pressure and temperature as close to the design value as possible.

To make the system operate economically should be another consideration in addition to meeting the need of the users. This depends to a degree on the control system.

The control system for district heating usually can be divided in accordance with the division of the system processes into subsystems and variables which must be controlled.

The requirements of individual processes are described below.

2.4.2 Control for deep well pumps

The function of the deep well pump can be compared with a source in an electric circuit. To control the pump is to control the source of the whole system and make it meet the system water demand. Generally speaking the deep well pump should be automatically controlled according to the flowrate required by the system. Since the pumping cost is a considerable part of the operating cost of the system, the pump control system should be designed to minimize as far as possible the electrical power required.

To prevent cavitation the pump must operate at a given NPSH (net positive suction head). Therefore a pressure signal or drawdown signal may be necessary to stop the pump before the water level in the well drops below a level corresponding to the NPSH.

2.4.3 Pressure control for water supply

A stable supply pressure is necessary for the pipeline system. The method of control depends on the configuration of the system.

A storage tank may be located high enough to create a static pressure which is sufficent to meet the pressure head requirements of the network. The hot water is then delivered from the storage tank directly and the supply pressure depends only on the elevation of the storage tank and the water level in the tank. This may be the best way to keep the supply pressure steady at a desirable level. To control the water level in the storage tank is to control the supply pressure.

The storage tank generally has a volume corresponding to at least 4 hour's of the system water demand. The water level will fluctuate slowly compared to the fluctuation of the flowrate in the main pipeline. For instance, if the tank is 30 m high above the network and the water level in the tank is 10 m, the supply pressure will be about 4 bar. If the diameter of the tank is 15 m, then a drop of one meter in water level can deliver 180 m^3 of hot water. Even if there is no water injected into the storage tank the supply pressure decreases only by 0.1 bar in one hour for a system with a flowrate of 180 m^3/hr. Actually the storage tank acts as a low-pass filter since it absorbs the fluctuation of load and supplies a steady pressure for the system.

If the conditions for installing a high level storage tank are not favourable, the supply pressure can be controlled by throttling the flow from the booster pump.

The main reason for controlling the supply pressure is to ensure that the pressure does not exceed the pressure that the pipe can endure and that it does not fall below a minimum pressure of 1.5-2.0 bar at the intake of the least favourably located user in the system network.

2.4.4 The water level control for degasser tank and storage tank

The purpose of water level control in the degasser tank is to maintain a certain retention time in order for the oxygen and other gases in the geothermal water to be released. It is well known that oxygen in the water is the main reason for corrosion in the pipelines and other equipments of the heating system. The releasing speed depends on the temperature of the water, the pressure in the tank, etc. This process needs a given time to reach equilibrium. The retention time depends on the volume of the tank, water level in the tank and the flowrate in both the injection pipe and discharge pipe.

The aim of controlling the water level in the storage tank is to keep a certain volume of water available to adjust the unbalance of the system demand over the 24 hours of a day. The storage tank is also called a peaking/back-up unit, the water level also affects the supply pressure if the water is delivered directly from the tank as discussed earlier.

The method for water level control may vary depending on the design configuration of the system. Two alarm signals are necessary for the operator. One is a high level alarm to prevent overflow, the other is a low level alarm to prevent drain up.

2.4.5 Water temperature control

If the temperature of geothermal water is above 90°C, it is common to install a double pipe system to get return water mixed with hot water and reach about 80°C. Normally the nominal temperature of the return water is about 40°C. The mixing point should be chosen in a place where the pressure and temperature are stable and controllable. Usually it is selected on the discharge side of the booster pump (in the Reykjavik District Heating System) or on the suction side of the booster pump (in the Seltjarnarnes District Heating System). (see Fig. 2-5).

In order to maintain the supply temperature constant some control loops are used. In the Seltjarnarnes system, the pressure of the hot water from the degasser tank is controlled by the water level in the tank, which keeps it almost at a steady value. The return water pressure is controlled by P_b and V_4 (Fig. 2-5), whereas the output temperature of the water is mainly controlled by the opening of V_3, i.e. the flowrate of the return water.

Several different technical approaches to maintain the supply temperature constant may be used. As an example, in the Reykjavik District Heating System, the control loops are:

a) return water pressure control (P_r, V_r); b) output pressure control (P_o, V_o); c) output temperature control (T, V_T)

The output temperature is mainly controlled by the flowrate of the hot water (see Fig. 2-5).

2.4.6 Pressure control for return water

The pressure of the return water must be controlled so that even at the highest house in the double pipe system the return water does not vaporize in the return pipeline and the pressure of return water must not be too high so that the lowest house can discharge the used water into the return water pipeline. This control is effected at the pumping station for the whole double pipe system.

2.4.7 Flow regulation

The system flowrate must be regulated in accordance with daily and seasonal fluctuation in the demand for water.

There are many methods for regulating the flow and it can be regulated at different points in the system. Basically the flow must be regulated by controlling the flowrate from the borehole pumps. Typical specifications of this kind of pumps are shown in Fig 2-6.

The system load curve can be described as follows:

$$H_s = H + aQ^2 \qquad \text{(eq. 2.4-1)}$$

H_s is the pressure head needed by the system to support the flowrate of Q, and H is a static pressure head differential between the water level in the well and the water level in the degasser tank. The coefficient, a, represents the resistance of the system.

The operating point of the pump is at the intersection of the performance curve and the load curve of the system, the load curve moves up as the well is drawn down and the operating point changes correspondingly.

If the pump is a constant speed pump, the performance curve of the pump cannot be changed. The flow regulation is then achieved by changing the form of the load curve, usually a control valve is used for this purpose. However some energy is lost in the valve. Another way is to shunt the flow from the discharge side to the suction side of the pump by a control valve (see Fig. 2-6). The second method is even more costy in terms of energy than the first one.

The best flow regulation method may be the use of a variable speed pump. In order to change the speed of the pump one usually employs a variable frequency power supply unit, which changes AC to DC and then converts DC to variable frequency AC. The revolutions per minute of the motor are dependent on the supply frequency so that the motor driven pump can operate at variable speed.

Assuming that the pump efficiency remains constant despite changes in the speed the following relations hold according to the similarity law:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \;; \quad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 ; \quad \frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3 \qquad \text{(eq. 2.4-2)}$$

From Fig. 2-7 we can see a cluster of curves which describe the performance of the variable speed pump. Theoretically, it is possible to operate the pump at any point along the load curve. Actually, it should work within a certain minimum and maximum speeds considering the efficiency of both the motor and the pump.

The advantage of the variable speed pump is the saving in the pumping cost (Ref. 3). For instance, assuming that a system load curve is proportional to the square of the flowrate, a reduction in flow rate obtained by reducing the pump speed down to one half will result in a reduction in power consumption to 1/8th of the original power. The same reduction in flow rate produced by the throttling method will only decrease the electric power consumption to about 1/2. Actually the power reduction is less than 1/2 because of the flat power consumption curve.

It turns out that the use of a variable speed pump may save up to 50 per cent of electric energy. It is therefore important to make full use of the variable speed pump if it is available in the pumping system. Although the initial cost of the variable speed pump will be high, the cost of electric power is significant for a district heating system where the pumping cost is one of the major operating costs. The variable speed pump should be controlled automatically according to the change in the flowrate of the system.

2.5 Requirement for computer monitoring and control system

2.5.1 Introduction

The monitoring and supervisory control system is at a higher system level than the process control. The aim of the system is to collect information from the processes of the whole system in order to represent the state of the operation, such as the major system variables, alarms and the status of equipments etc. This system must also be capable of controlling the activities of individual processes either manually (remotely) or automatically depending on the system configuration.

2.5.2 Scanning time

In the district heating system, most of the instruments that measure the system variables are analog meters and on/off position sensors. The digital monitoring and control system must scan them in a certain time interval. It is estimated that pressure, which is the fastest changing variable in the geothermal district heating system, must be sampled at an interval of a few seconds by the supervisory system. Most monitoring and control systems available can meet this need assuming that the computer and communication channels have sufficient capacity. However further investigation of the sampling frequency must be undertaken.

2.5.3 The variables to be monitored

The system variables which may be fed back to the supervisory monitoring and control system include analog measurements, status signals, setpoint signals, alarm signals and accumulating pulses. The monitoring system must collect them for storage or display in a suitable format.

note: "*" stands for optional signals,

A) Analog signals:	
pressure:	-- at the well head of each well -- supply pressure at discharge side of the booster pump -- return water pressure * pressure at selected points in the network
temperature:	-- supply water temperature -- return water temperature * at the well head of each well
flowrate:	-- at well head of each well -- flowrate from the degasser tank * supply flowrate to the system
level:	-- water level in the degasser tank * drawdown of each well
B) Control signals:	-- opening of the control valves -- setpoints of each process controller
C) Accumulating signals:	* accumulated flow of each well * accumulated flow of water supplied into the system

* accumulated electric consumption

* accumulated working hours of each pump

D) Status signals:

-- on/off state of each deep well pump

-- on/off state of each booster pump

E) Alarm signals:

-- high and low water levels in the degasser tank

-- high and low pressure of the supply water

-- high pressure of the return water

* high and low temperature of the supply water

All the main variables should be scanned with an interval of several seconds, but printed with a minimum interval of ten minutes. The scanning time and printing time interval can be changed by the system operator according to the operating experience.

In order to alert the operator alarms should be represented by different colours or different frequencies of the audible signals.

The setpoint of each process controller is not changed frequently in operation and can be entered manually into the computer for display in the schematic diagram on the screen.

It may be too expensive to measure the flowrate of each well but it is important information for reservoir estimation.

Most of the accumulating signals can be omitted if the computer and system program are used to compute these quantities.

The alarm signals can be given by setting the limit values for each variable, using computer to compare them with the actual values. If they are beyond the the set values, then the alarms are given. However, it is safer to use separate signals than using the method described above.

2.5.4 Requirements for computer control

The district heating system is a dispersed system which is spread over the whole area it serves. It is desirable to control the system centrally.

The Seltjarnarnes District Heating System is managed by single operator. From this point of view the control system should be as complete as possible. On the other hand, the system is comparatively small,so that it is not reasonable to spend a lot of money on the control system. Therefore the control system should meet the following basic needs:

1. The system operator should be able to get the main information about the system operation in the control room located at the pumping station. In order to have an overview of the system operation it is desirable to use a CRT for displaying the system schematic diagrams with the main variables, status of the devices and alarms indicated on the screen. This includes the situation of the deep well pumps and the control loops, as well as the degasser tank. A possible schematic diagram for the display is given in Fig. 2-10.

2. The supervisory control system should be able to control the main variables automatically or manually in the control room. The required manual intervention should be as little as possible. If some manual control is needed, it should be executed in the control room.

3. The control system should be able to maintain the operational records that contain the real time,the main variables, alarms when they appear, and some accumulating values.

Some additional requirements for the computer can be mentioned:

- The system computer should be able to control all the process units existing today and be able to accommodate future system expansion.

- The system should be easy to use for the operator who may have minimal knowledge of computer hardware and software.

- The system should be realiable and have an auto/manual function, in case of computer failure, so that the system operation is not severely affected.

- All the control programs should be stored on the floppy disk and loaded into the main memory of the host computer and then download into the memory of the microprocessor-based controller.

- The system should be able to restart the control and monitoring function automatically after a power system failure.

- The system should offer a real time clock, with hours, minutes, seconds, month and year and it should be able to print a log journal.

- The alarms should be displayed on the screen and blinked to alert the operator. Alarms should be disabled when the operator acknowledges them. All alarms should be logged on a printer.

The monitoring function should execute regularly and display the variables on the screen. It should also be able to log them on a printer in the format needed, different variables may have different time intervals for logging, some of them may be in hours, some in minutes, etc.

The system should have statistical functions, gathering the data and processing them and printing data in desirable formats on a daily, monthly, yearly basis.

The system should be able to deal with the schematic diagrams on the screen with the value of the parameters, status and alarms in the designated locations and update them with a suitable time interval. With the schematic diagram program it should be easy to generate new graphic displays and modify the existing ones.

2.5.5 Schematic diagrams and printout

The overview of the district heating system should be displayed on the CRT in the form of schematic diagrams with parameters, status and alarms. If needed it should be divided into several pages. The opening of the valves and switches should be shown by graphic symbolsora colour change.

The printout should include the record of real time operations with a daily report, monthly report and the report for a year of operation.

The computer should be able to make simple on line calculations such as total flow, total power consumption etc, and count and process input pulses from flowmeters. The accumulated flow and power consumption should be displayed on the CRT and logged on printer. Also it should be able to measure the running time of theelectric motors, which is an information for the maintainance of the device.

It should also be mentioned that there is another possibility for controlling the three deep well pumps. It is reported that a Danfoss controller is available with the capacity of controlling several constant speed pumps and one variable speed pump atthe same time according to the different setpoint of the pressure in the discharge side of the pumps.

A simulation program should be included in the system program for the existing district heating system, which is always faced with the problem of system expansion. The system simulation will give the manager and designer valuable information about the existing situation and how it can be expanded as well as the effect of expansion on the existing network.

Tranducers and front-line controllers: all the tranducers should use standard intput signals, i.e. 0-20 mA, 4-20 mA, 0-10 V, or 0-1 v, and with the accuracy better than 1% of the full scale.

TABLE 1 Chemical composition of thermal fluid from Seltjarnarnes

Well No.	Sn-4	Mg mg/l	0.09
Sample No.	83080215	CO_2* mg/l	7.5
Temperature °C..	114	SO_4 mg/l	228.8
Conductivity Ωm.	3.1	H_2S mg/l	<0.2
pH/°C	8.47-22	Cl mg/l	989.8
SiO_2 mg/l	99.9	F mg/l	0.72
Na mg/l	434.6	Total dissolved solids	2238.8
K mg/l	10.3		
Ca mg/l	240.5		

* Total carbonates as CO_2.

3 CANDIDATE SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM FOR THE SELTJARNARNES DISTRICT HEATING SERVICE

3.1 General configuration

In this chapter a SCADA system configuration for the Seltjarnarnes District Heating Service is roughly outlined (Fig. 3-1, 3-2). The SCADA system is composed of the following components:

1) Host computer and peripherials: keyboard, CRT; printer and disk drive; 2) Industrial microprocessor-based controller; 3) Tranducers and front-line controllers

The industrial microprocessor-based controller connects all the sensors, tranducers and actuators to its input and output lines and it is also connected to the host computer through the communication line. The host computer links its peripherials: disk drive, CRT, printer and keyboard.

The system program is stored in the memory of the industrial microprocessor-based controller, it is downloaded from the host computer. The scanning and control functions are performed by the industrial microprocessor-based controller, but not the host computer. The daily work of the host computer is data processing: gathering, storing, displaying and printing data, providing dynamically updated graphical displays. It can also be used as a program development tool, system simulator and so on. Therefore the case of a host computer failure, the operation of the district heating system is still controlled by the industrial microprocessor-based controller. This obviously improvesrealiability of the system. If the industrial microprocessor-based controller is out of order the system should be capable of manual operation.

The industrial microprocessor-based controller is the heart of the SCADA system. There are many industrial microprocessor-based control system available, for instance, MAC 5000 (Analog Devices), PCI-3000 (Burr-Brown), IC-4422 (Analogic), RDC-3500 (Bristol Babcock), PM-550 (Texas Instrument), to name only a few and new industrial controllers appear continuously (Refs. 4,5,6,7). The common feature of this kind of controllers is that they are relatively inexpensive and flexible. They can be expanded easily by means of a card plugged into the motherboard for special tasks. They have one or two microprocessor units, sufficient memory for the operating system and user programs, standard communication ports interfaced to host computers and peripherials. They contained A/D and D/A converters as well as standard output modules for switching AC and DC power at various voltage and power levels. This allows the user to connect the cables from sensors, tranducers and actuators directly. Usually they have control modules for industrial controls, such as PID control, feedforward control, cascade control. (see Appendix A,B,C).

Because the standard communication channel is used in the industrial microprocessor-based controller, the host computer can be IBM PC/XT, APPLE, COMPAQ, DEC, HP, as well as other microcomputers since there are not many process variables to deal with in a comparatively small system (Refs. 8,9).

The operator panel may not be available. Since the Seltjarnarnes District Heating System is not large in scale, it is not reasonable to design a special operator panel. The computer keyboard might be used as an operator panel by defining some special function keys in the program.

All the variables are scanned by the industrial microprocessor-based controller, then transmitted to the host computer through the communication channels. The variables are stored on the disk, displayed on the CRT, and printed by the printer. If alarm signals are detected, warning and audible signals are given. The system scans the variables automatically and the latest value of the variables are compared with the previous values. If they are different, they will be updated on the screen with a time interval which allows the data to be conveniently read by the operator.

Based on the data gathered and control programs the industrial microprocessor-based controller controls the process variables automatically by sending control signals from its output line to the actuators. If the operator wants to intervene in the operation, he can use some defined keys On the keyboard to control the devices directly. Also, he can ask the system to display or print the data related to the alarm signals etc.

The format of the display might be as shown in Fig. 2-10. It can also be changed into any desirable format by the system schematic diagram program.

The operation reports to be printed can be divided into four types:

1) Operation record: This contains all the information during the operation in time sequence. The main data is printed regularly with a time interval which may be every half hour, between the printing periods the intervention of the operator and alarms should be printed.

2) Hourly operation report: This contains the main data and it is printed after 24 hours of operation. The data is printed with a certain time interval, say every half hour or every hour.

3) Daily operation report: The data is printed for every day of the month.

4) Monthly operation report: The data are printed for every month of the year.

The contents of different types of reports are stored in different files on the disk. The hard disk may be desirable since it has more capacity than a floppy disk and provides faster access.

Some variables such as the flowrate might be displayed or printed in the form of averaged values. It might be possible to omit some accumulating signals by calculating the sum of the values obtained in each scan divided by the number of scanning times in the printing interval.

Two methods can be used to get the flowrate of the supply water. One is to install a flowmeter in the supply pipeline which measure the flowrate, directly. The other is to install a temperature sensor before the mixing point of the hot water and return water, measuring the temperature of geothermal water and sending it to the computer, using the computer to calculate the flowrate to the supply pipeline according to the formula:

$$F_o = F_i\left[\frac{Ti - Tr}{T_s - Tr}\right] \qquad \text{(eq. 3.1-1)}$$

where the F_o is the flowrate to the supply pipeline, the F_i is the flowrate from the degasser tank, T_i is the temperature of geothermal water, T_r is the the temperature of the return water, T_s is the temperature of the supply water.

3.2 The control of the deep well pumps

As mentioned above one of the main costs of the system operation is the pumping cost. The control for the deep well pumps is therefore of interest. The main idea is to control their operation economically. There are three deep well pumps in the Seltjarnarnes system. Two of them operate at constant speed and one at variable speed, a forth will be added shortly. The setpoint of the variable speed pump is now controlled manually according to the system water demand. So that the advantage of the variable speed cannot be fully used. One solution is to use the microprocessor-based controller to determine and control the setpoint.

There are a number of control system configurations that could be proposed. One of them is described below. With adequate instrumentation in the system, sufficient data will be available for more effective control.

First of all, we should assume some reasonable conditions and simplify the system since the real system is too complicated to deal with. Some factors which are less important should be omitted.

A) The discharge line from the pumps join together just before injection into the degasser tank. We may neglect the resistance of the collecting pipe from the joint to the degasser tank. Furthermore, the water level in the degasser tank varies by a small value which provides a small contribution to the variation of the pressure at the joint. We assume that the pressure at the joint is a constant value which corresponds to the height difference between the joint and water level in the degasser tank, which is near the setpoint. Then each pump can be considered as operating independently.

B) The performance of each deep well pump is identical to that given by the manufacturers (see Figs. 2-7, 2-8, 2-9).

C) The efficiency of the deep well pump does not change when the speed of the pump varies through its operating range. The similarity law can be used to express the relation between speed (N), flowrate (Q) and power consumption (P).

D) Still we do not know the operating point of each constant speed pump since we do not know the flowrate from each well (there is not flowmeter in each discharge line from the wells). We assume that it is working in the range of high efficiency. Thus, the flowrate is about 70 m3/hr for well No.3; for well No. 5 the flowrate is 80 m3/hr.

Deep well pump No. 4 is chosen to operate at variable speed due to following reasons:

1. The capacity of this pump is the highest out of the three. The flowrate can be up to 180 m3/hr, giving it a wide range for flow regulation. Of course it requires the highest power. If it is controlled effectively the potential power savings are larger than for the other pumps.

2. The performance curve of pump No. 4 shows that it has a high efficiency over a wide flow range.

We then check the total flowrate of the three pumps to find out if they can be adjusted to provide a continuous flowrate between the minimum and maximum value that the system needs. The total flowrate can be expressed as:

$$Q_T = Q_3 + Q_5 + aQ_4 \qquad \text{(eq.3.2-1)}$$

Where Q_3, Q_5 and Q_4, are the flowrate of the three wells as numbered. they are 70 m3/hr, 80 m3/hr and 180 m3/hr depending on the load curve of the pipelines (the value assumed is based on a balanced design). Q_3, and Q_5 can be either 0 m3/hr or 70 m3/hr and 80 m3/hr by on/off control of the pumps. Q_T is the total flowrate that the system needs.

The factor a is n/N, where n: actual RPM of the pump and N is the normal speed for well pump No. 4 at 50 Hz.

By controlling the on/off state of the well pumps No. 3 and No. 5 and control n, the total flowrate can be continuously regulated from 0 - above 300 m3/hr without any gap during the value change in Q_3 and Q_5.

The control method is clear: assume that Q_4 is 150 m^3/hr (the real value is defined by the resistance of the transmission line). When the flowrate indicated by the flowmeter is less than 150 m^3/hr, only the variable speed pump is operating. By changing the speed , the flowrate can vary from 0 to 150 m^3/hr. When the flowrate is larger than this, say 180 m^3/hr, then one constant speed pump is started. By controlling n, the flowrate can be changed from 70 to 220 m3/hr. When the flowrate is larger than 220 m3/hr, another constant speed pump is started, and the flowrate can be varied from 220 to 300 m3/hr.

The water level in the degasser tank may also be used as a variable for control. The relation between the water level and flowrate can easily be found and it is quicker and safer than using flowrate only as the main control variable, because the use of water level can prevent overflow from the degasser tank.

It should be pointed out that a tolerance L for the setpoint of the water level in the degasser tank is necessary to prevent the constant speed pumps from being selected on/off too frequently in the flowrate around the limit point, i.e. 150 m3/hr, 220 m3/hr and 300 m3/hr. Trend analysis methods might also be used to decide whether a constant speed pump should be started or stopped when the flowrate is near the limit point, and also the minimum speed and maximum speed for the variable speed pump should be defined. A possible control flowchart is given in Fig. 3-3.

The valve V4 must still be used, not as a main control valve, but only as the backup control valve in the event of automatic control system failure and as a safety device to prevent overflow when the water level reaches the top of the degasser tank. If overflow occurs the alarm signal is activated and V4 will be closed automatically. (see Fig. 3-2).

3.3 Costs and benefits

Sufficient data both on the cost of equipment and data on system operation are unavailable. A rough estimate for the cost of the prepackaged system of the host computer with peripherals and industrial microcomputer-based controller is about twenty thousand US dollars. Further investigation should be carried out for finding a SCADA system which is suitable for a small system.

It is difficult to describe the benefits of the proposed control system accurately at this point. However it is clear that the following general benefits will be gained when a SCADA system is operational:

1) Because the main information about the system operation is available from the SCADA system, the operator can manage the system with more confidence and with improved visibility of the system's state. The system can be operated closer to its desired operating point and system malfunctions can be detected faster from the central facility.

2) The pumping cost may be reduced by improved control of the pumping system. That is the direct benefit that may be gained soon after the SCADA system is put into operation.

3) The operational data which is collected by the SCADA system, makes it possible to determine how the system operation could be improved.

4) The SCADA system reduces the operator's workload. The main operations are done automatically or manually from the control room instead of going to the dispersed sites to read the indicators and operate the pumps and valves. The operator will have more time for other duties.

4 SUMMARY AND RECOMMENDATIONS

It is most desirable that a dispersed geothermal district heating system, such as in Seltjarnarnes, should be controlled centrally and it is feasible to use a relatively inexpensive industrial microprocessor-based controller and a standard microcomputer (as the host computer) system to form a SCADA system that formerly required much larger and more expensive equipment. With increasing water demand the new borehole (borehole No. 6) will be put into operation and the necessity for automatic or central control will be more imperative.

The improvement in the operation of a district heating system should be concentrated on cutting down the consumption of electricity by an automatic control system. The accuracy is of less importance compared to the chemical and machine processing industries.

The first step of automation the system should be to improve the instrumentation if for some reasons the SCADA system cannot be employed at the moment.

It is suggested that a variable frequency power supply unit might be used for the booster pump, i.e. to change the booster pump to variable speed operation. The pressure control valve for water supply to the main pipe can then be omitted, and the energy loss in that valve will disappear.

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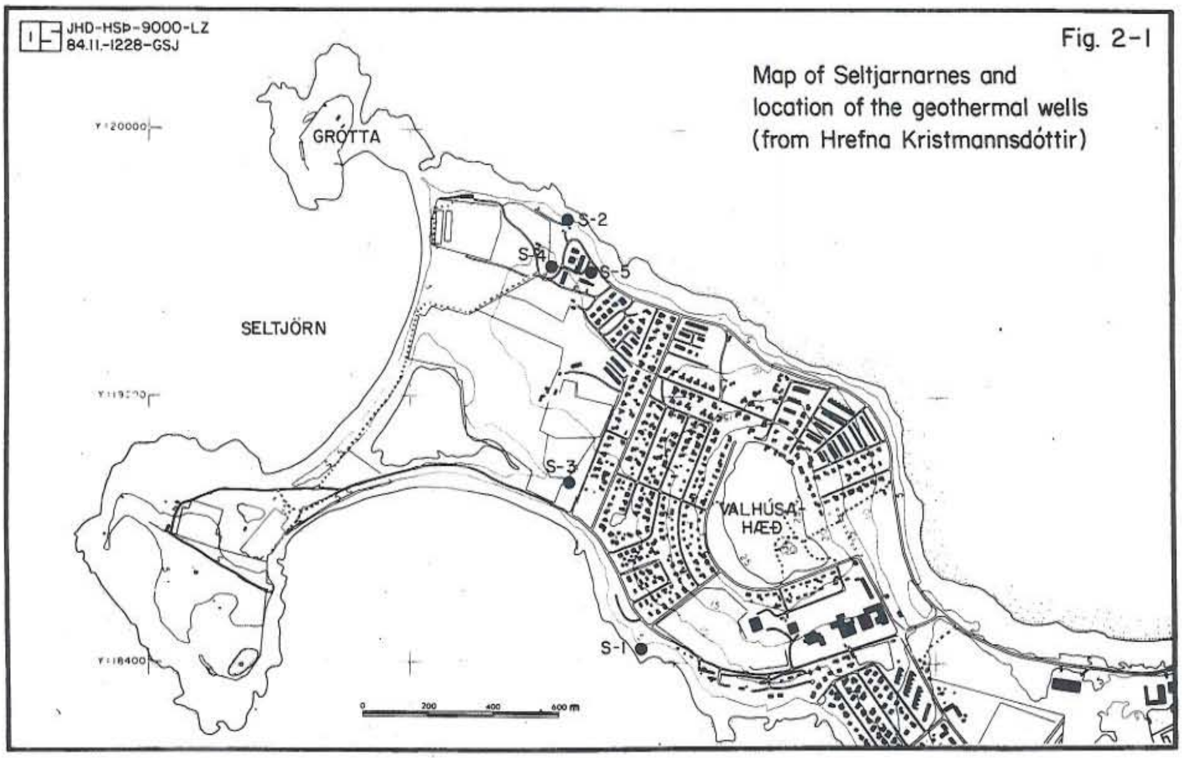


Fig. 2-1

Map of Seltjarnarnes and location of the geothermal wells (from Hrefna Kristmannsdóttir)

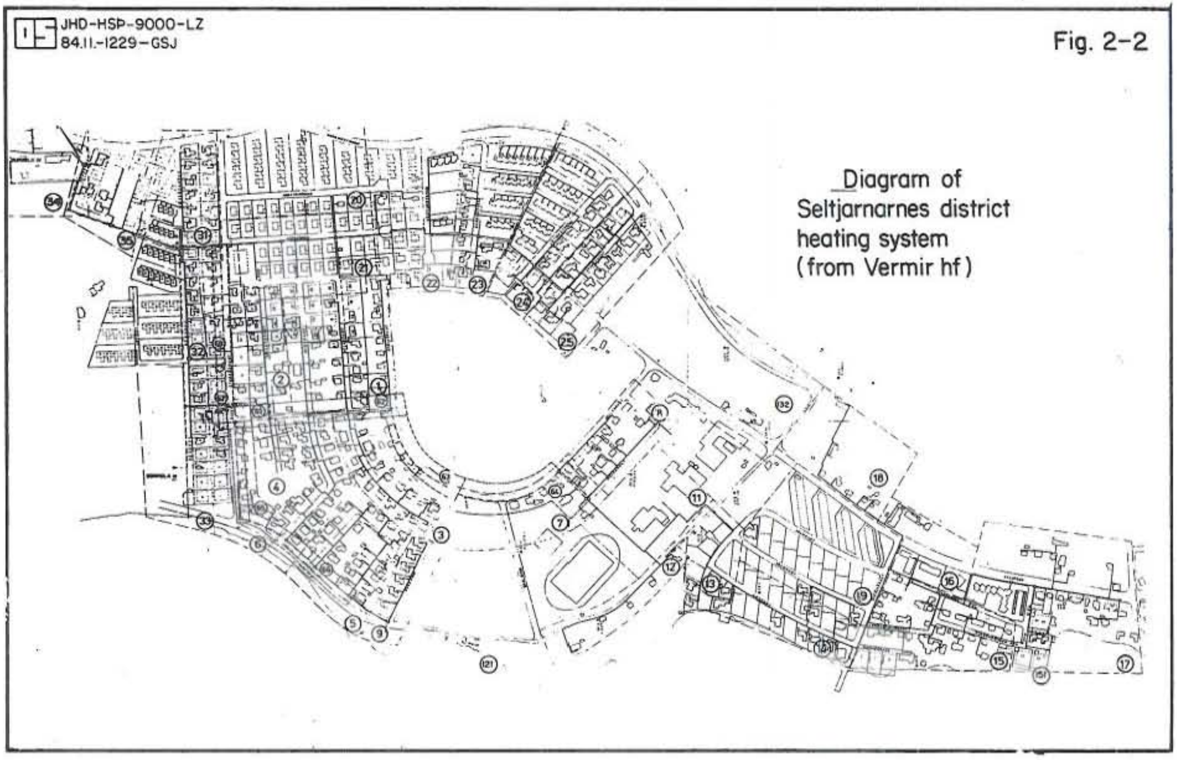


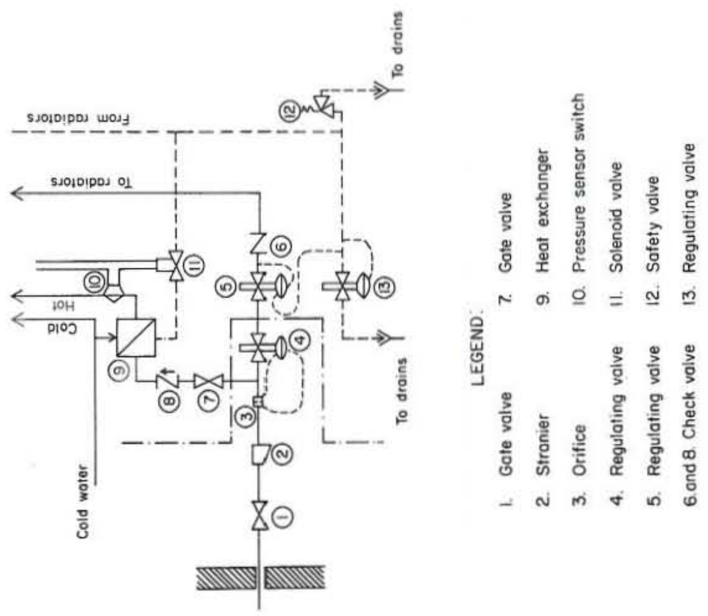
Fig. 2-2

Diagram of Seltjarnarnes district heating system (from Vermir hf)

JHD-HSP-9000-LZ
84.11.-1227-GSJ

Fig. 2-3

Typical house connection in Seltjarnarnes district heating system (from Thorbjörn Karlsson)



LEGEND:

1. Gate valve
2. Stronier
3. Orifice
4. Regulating valve
5. Regulating valve
6. and 8. Check valve
7. Gate valve
9. Heat exchanger
10. Pressure sensor switch
11. Solenoid valve
12. Safety valve
13. Regulating valve

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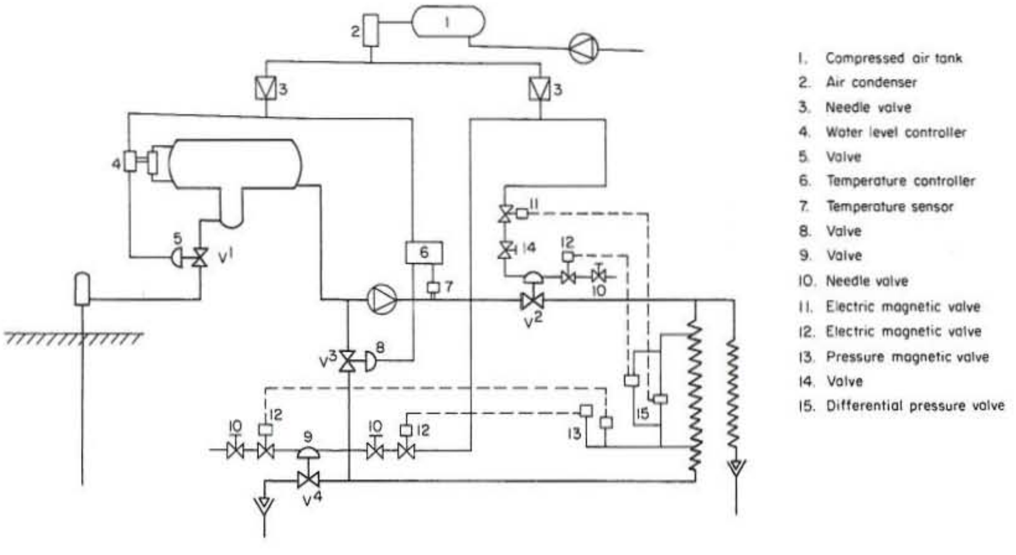
Fig. 2-4

Diagram of the original control system design (from Vermir)



1. Compressed air tank
2. Air condenser
3. Needle valve
4. Water level controller
5. Valve
6. Temperature controller
7. Temperature sensor
8. Valve
9. Valve
10. Needle valve
11. Electric magnetic valve
12. Electric magnetic valve
13. Pressure magnetic valve
14. Valve
15. Differential pressure valve

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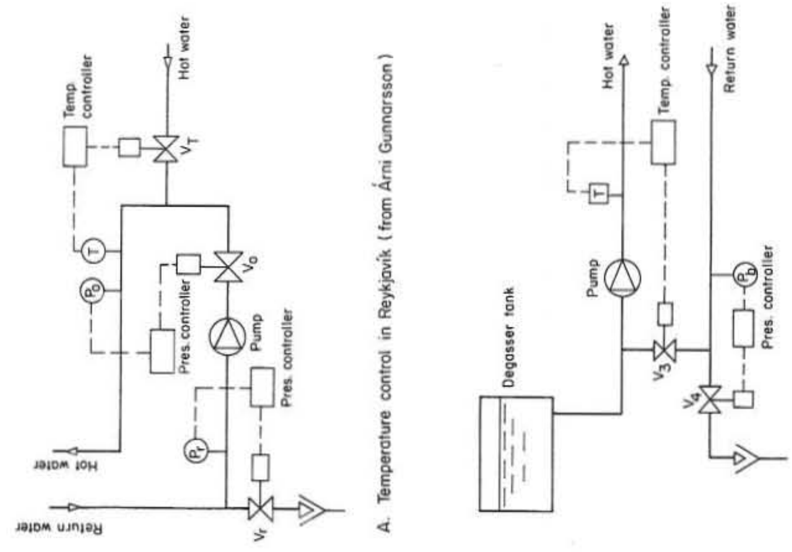
Fig. 2-5

Temperature control in Reykjavík and Seltjarnarnes district heating systems



A. Temperature control in Reykjavík (from Árni Gunnarsson)

B. Temperature control in Seltjarnarnes (from Vermir hf)

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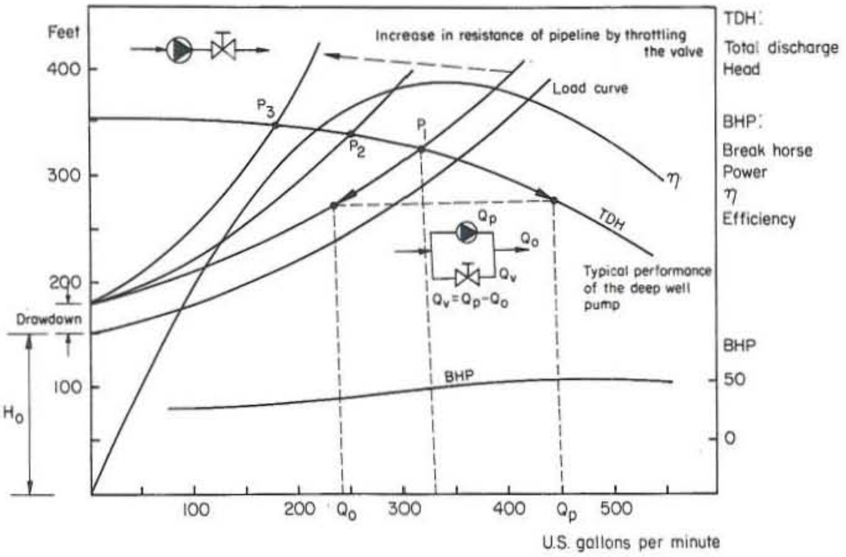
Fig. 2-6

Flow regulation of the pumping system



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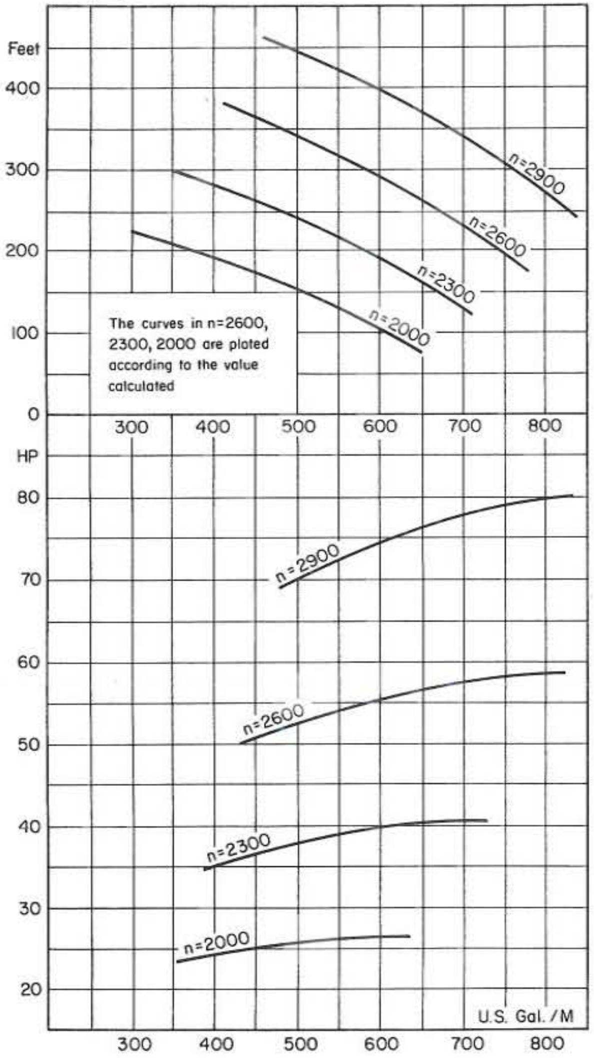
84.11.-1223-GSJ

Fig. 2-7

Pump performance in well No.4 (from Vermir hf)



The curves in n=2600, 2300, 2000 are ploted according to the value calculated

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Fig. 2-8

Performance of pump No.3 (from Vermir hf)

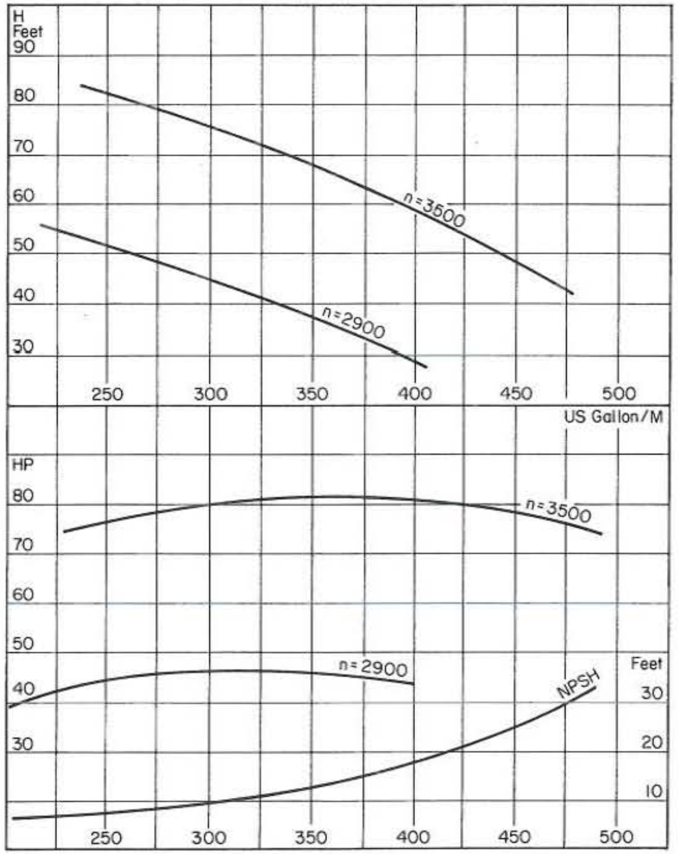

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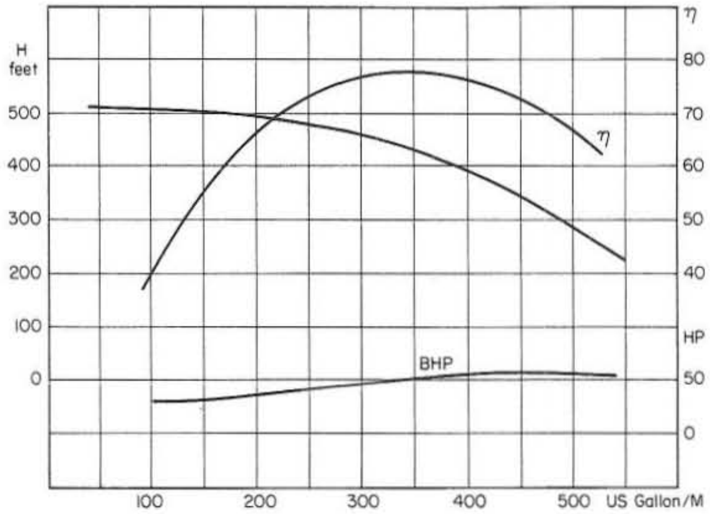
Fig. 2-9

The performance of pump No.5 (from Vermir hf)



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84.11-1220-GSJ

Fig. 2-10

The form of system display

ALARM AREA

HLA : HIGH LEVEL ALARM for degasser tank
LLA : LOW LEVEL ALARM for degasser tank

HPA : HIGH PRESSURE ALARM for supply water
LPA : LOW PRESSURE ALARM for supply water

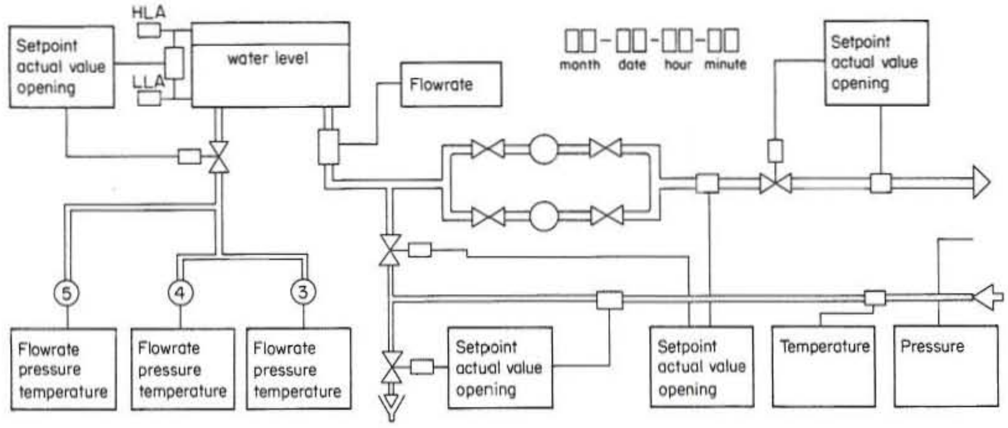

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Fig. 3-1

Schematic diagram of SCADA system

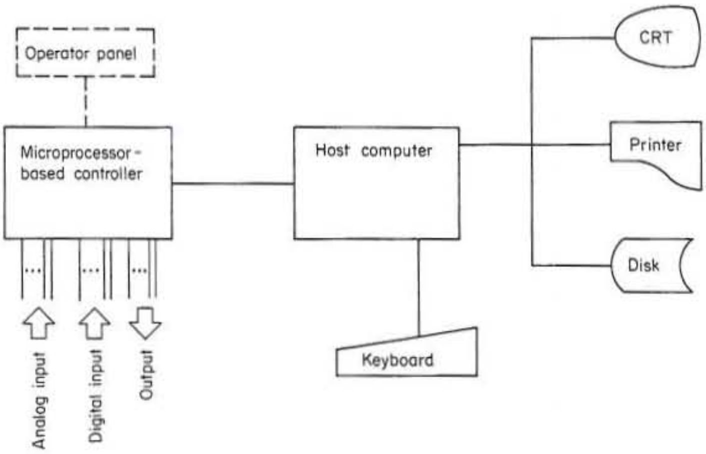

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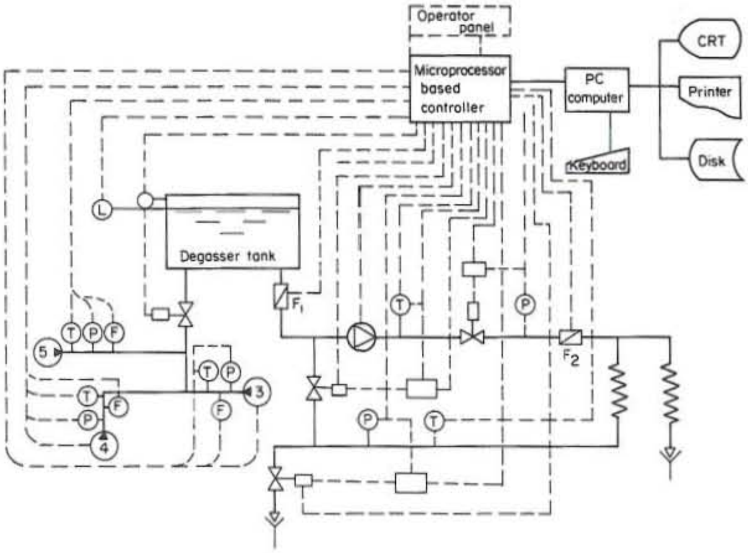
Fig. 3-2



General configuration of SCADA system

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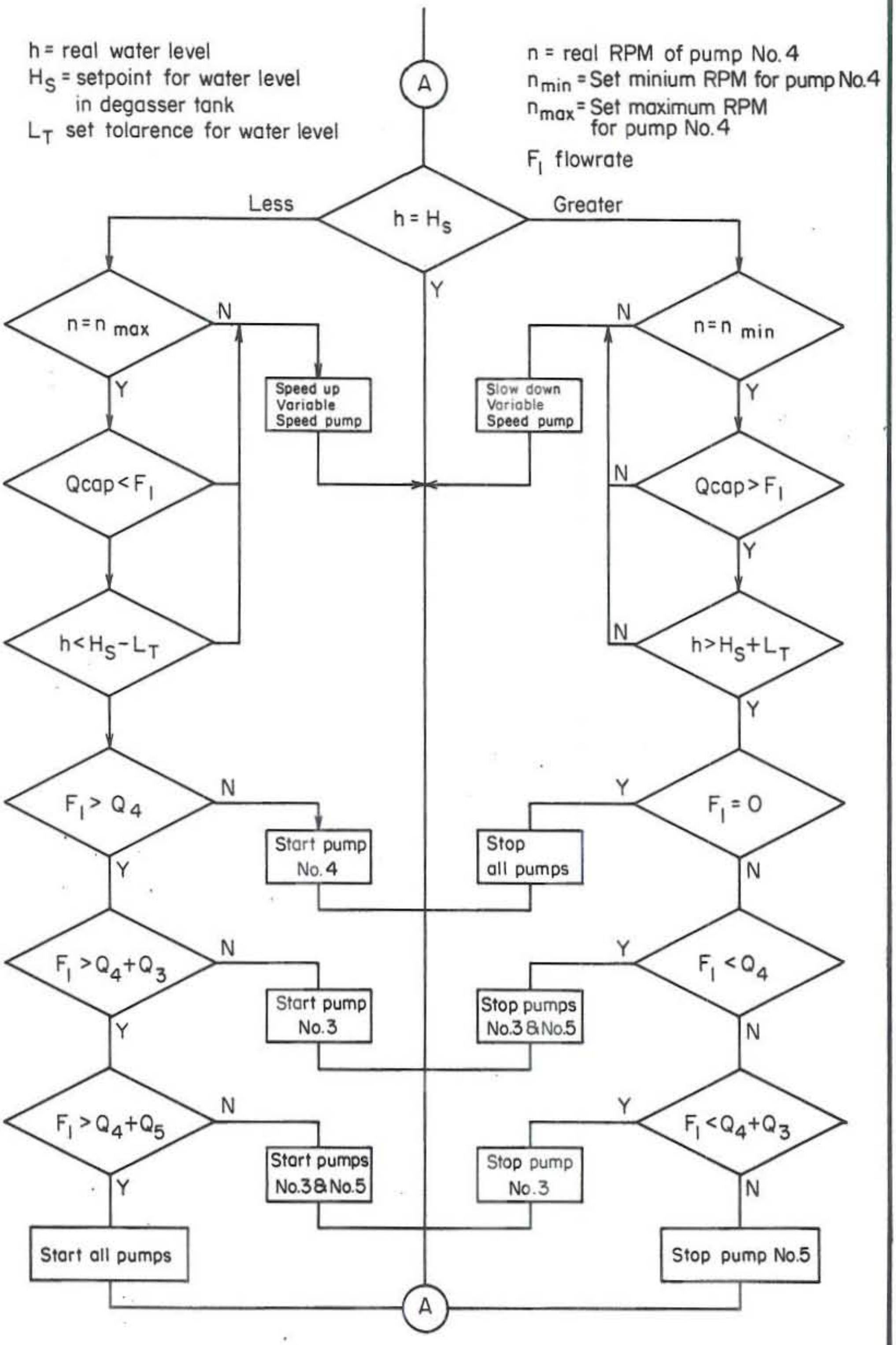
Fig. 3-3

Control model for deep well pumps



APPENDIX A

THE SPECIFICATION OF MAC-5000

1. INPUT TYPES:

   12 channels, mix and match; Thermocouples: J, K, S, R, E, B, W (linearized); RTD: 100 Platinum (linearized); Stain gage: 30 mV and 100 mV spans; DC voltage: 25 mV to 10 V; Process currents: 0-10 mA, 4-20 mA, 0-20 mA.

   Inputs selectable by 4 channel OMX module-mix; 3 types per board. OMX 03, 04 modules isolated to 1000 V channel to channel, input-to-output with IEEE-472(swc) transient protection. A/D converter: 14 bit integrating.

2. DIGITAL I/O:

   8 channels of isolated or contact closure inputs; 8 channels digital outputs; connector-compatible with MAC-4020 high level solid-staterelay system.

3. PULSE INPUTS: (optional use of two digital input)

   2 channels of fequencyor pulse accumulator input; 32 bits pulse accumulation: 20 Hz max.frequency.

4. COMMUNICATION PORTS:

   4 wire full duplex; 256 byte RAM buffered: asynchronous selectable baud rate: 110 to 19.2K baud distance: 20 mA 10,000 ft (3048m); RS-232 50 ft (15m); RS-422 10,000 ft (3048m); RS-423 1000 ft(305m)

5. 8088-BASED MICROCOMPUTER:

   32K RAM. - expandable; 80K PROM; 16K user PROM socket

6. POWER:

   On board ac power supply: 110V / 115V / 220V / 240V or 24V dc(used for primary or back-up to ac line)

7. ENVIRONMENTAL:

   Operating temperature: 0 to 60; Humidity: meets MIL-STD 202, method 103; Vabrition. meets MIL-STD 167-1; Magnitic immunity: 5W 27 MHz 3 feet.

APPENDIX B

PCI-3000 SYSTEM SPECIFICATIONS

Expandability: Up to 1024 I/O channels per master, plus expansion enclosures; up to 16 I/O boards. Up to 31 masterscan be networked along a single multidrop communication line from a host computer.

Communications: Two asynchronous serial channels RS-232 signals on both channels RS-422 signals on one channel 300-900 baud IEEE-488 (see option below)

Memory: 16K bytes system EPROM 2K bytes system RAM 32K user expansion space

Microprocessor: Z80A

Temperature range: 0 to 50°C

Options: IEEE-488 connector communications capability

Power supply: 85 to 130V AC, 50-60 Hz 200 to 260V AC, 50-60 Hz

Analog input: 10 mV to 10 V direct inputs (high voltage inputs possible with atenuation added to termination panels); Programmable gain (1 to 1000) 12 bit resolution

Pulse output available: Programmable duty cycle frequency up to 2 MHz

Counters: frequency up to 4 MHz accumulation 16 bit resolution

Digital input and output: 24 mA current sink 15 mA current source TTL compatible switch up to 3 A voltage isolation (4000 VAC/DC)

APPENDIX C

INTRODUCTION OF PM-550 PROGRAMMABLE CONTROLLER

1. INTRODUCTION

The PM-550 programmable control system is a modular industrial control system that is designed for controlling small to medium sized process, it can execute on/off control, as well as feedback loop control. It can be divided into main 4 parts: central control unit and power supply; input and output modules; operator interfaces; programming and troubleshooting tools.

The central control unit (CCU) makes all the logical decisions and performs all the mathematical computations required by the application program. It also controls; 1) communications with the system, 2) on-line and off-line self diagnostics and, 3) timing and control, 4) data signals for the input and output devices.

The input and output modules provide the electrical isolation and signal conversion required to interface the logic level signals inside the system with the various voltage and current signals used by field devices such as limit switches, motor starters, temperature transmitters and valve positioners. Both discrete I/O and analog I/O are available.

The operator interfaces device (TCAM) give the operator ability to easily monitor and control the timers, counters and analog control loops in the system.

The programming and troubleshooting tools are used for programming and troubleshooting, training in system use and operation, process simulation for control system checkout.

2. SPECIFICATIONS

Memory size: Logic program 2048/4096 words; variable data 1024 words; constant data 1024/2048 words; Programmable unlimited (TCAM will display the timers, first 99 timers and the first counters 99 counters.

Functions: Combinational logic; 8 PID analog loop controls; floating point and integer calculations: add; subtract; multiply; divide; compare; data move; conditional end of scan.

Special functions: entry point; convertion of binary and BCD; convertion of binary and engineering units; square and square root integer and floating point; sequential and correlated data table; message generation - ASII string; fall-through shift register input; asynchronous shift register output

Auxiliary functions: single scan option; cassette tape load, verify, dump program and memory list download to print terminal

Scan time: Less than 20 msec. for 2k logic memory 500 msec. processing 8 analog loops.

Input/output: 96 discrete I/O, expendable to 512 I/O 64 analog and/or word I/O.

Communication: IBM 2260 protocol based 1 port differential line, 9600 baud (RS422) 2 ports EIA RS232C, 300/1200 baud.

Diagnostics: Fault relay contacts for alarm shutdown on fatal errors; self-diagnostics with error tables.