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COMPUTER CONTROL SYSTEMS OF HYDRAULIC NETWORK CONTROL CENTER FOR HIGH EFFICIENCY OPERATION

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I. INTRODUCTION

Demands for electric energy are continuously increasing every year. To cope with the situation, nuclear power stations and thermal power stations (using not only oil but also coal) are being built one after another, and recently, more effective use of water resources are re-examined among the people concerned.

One of them is a peak load hydraulic power generation to cope with the increased load fluctuation width during daytime, and the other is an improvement of discharge regulating ability in a small size hydraulic power station for minimizing the non-effective discharges.

When examining more efficient use and control of water, however, first of all, the River Law which stipulates "An artificial flood due to a rapid discharge or destruction of the nature due to a change of environment shall not be made" must be taken into considerations. To use the limited water resources most effectively, necessary data must be obtained quantitatively for the most pertinent judgement, and the conventional method which relied upon a perception must be avoided.

Computer control systems of hydraulic network control centers are introduced by reporting actual cases.

II. TENDENCY OF COMPUTER CONTROL SYSTEMS OF HYDRAULIC NETWORK CONTROL CENTER

In the control of hydraulic system, the limitations and conditions for actual operations greatly differ depending upon the geographical configurations and the amount of rainfall at the objective hydraulic network. Further, the operating policy is greatly affected by each generator output, and their positions in the power network systems. Consequently, configurations of computer system to be employed and its size differ in response to the above mentioned various conditions. The recently employed computer systems are so designed to supervise and control a wider areas for increasing the overall efficiency of hydraulic system rather than for each one of the dams.

1) Each dam and power station (hereinafter, a power station is abbreviated to as PS) are joined to the system with a remote supervisory controller (hereinafter called "telecon"), and recently, in most cases, they are coupled with a computer with data exchangers using a micro-processor.

Keeping a pace with the advancement of LSI technologies, micro-processor application technique has been improved, and smaller in size but more reliable micro-processors have been made available. It is assumed that micro-processors will be employed more and more because it is possible to cope with a difference between various telecon systems, and with a future expansion or modification of a system through software technic. The data exchangers function expands to transfer data not only to a computer but also to system panels, operator's consoles and other places, and further higher reliability can be obtained by making it to a duplex system for significant portions.

2) As well as the micro-processor and data exchanger, a CPU which functions as the core of a system has been fullfilled with RAS functions. And, reliability of the system has been far increased by employment of high level languages in the software, standardization of program, promotion of program package, etc.

3) In many cases, CRT displays have been employed for man-machine interfaces, and it is now possible to visually confirm data for overall systems in a moment. Further, with results of various arithmetic operations and displays using graphs, it is possible to grasp overall system data quantitatively, and it has become possible to expect an improvement of controlling quality.

4) For the most optimum controls and operations under various limitations and conditions, such as flood forecasting, distributions of power generator efficiencies, actions to be taken at the time of an abnormal flood and processings in the case of a flood, use of a computer is indispensable.

5) Because of the needs as mentioned above, accumula-

tions of the actual operating performances in the past and advancements of various equipment, functions of a system have been expanded from the very beginning functions such as indications of various calculations and loggings to automatic operation control of power generators and automatic control of flood discharge gates.

A number of systems are still of a semi-automatic type, however, it can be said that we are now in the areas where we can actually develop an unattended dam control and full-automatic hydraulic network control.

6) Yet, to make a full automatic system, not only a very high reliability but also verifications of supervisory control system under various cases are required. Particularly, in a hydraulic system, there are various phenomena such as flood status at an upstream and swing of a dam water level which are hard to find correctly. Even a pondage or volume of discharged water, it cannot be found accurately.

Consequently, various constants, etc. for experimental equations must be optimized in the actual operation developing process.

7) At the same time, for a flood, it is necessary to verify it with the simulation which models a characteristic case based on the data accumulated during past years. For this purpose, a dam simulator equipment has been used. The dam simulator equipment dummy-outputs water level fluctuation of each hydraulic network every hour and changes gate opening through an operator control.

8) The dam simulator is useful not only for verification of a system but also for training of an operator, and in the recent systems, the dam simulator has occupied the significant position.

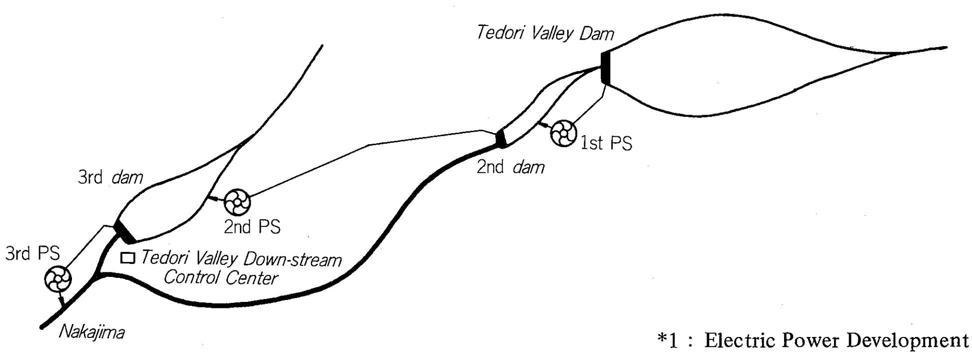
9) In the future, importance of a software will further increase and allotment of duties to be accomplished by a computer will be expanded. However, still a judgement by human being is required for an abnormal flood, etc. which are not recorded in the past data. For this reason, a sufficient consideration must be given to the idea how the duties should be distributed to a computer and human being and how the computer and human being should be communicated mutually.

III. COMPUTER CONTROL SYSTEM OF HYDRAULIC NETWORK CONTROL CENTER AT THE DOWN-STREAM OF TEDORI VALLEY OF THE HOKURIKU ELECTRIC POWER CO., INC.

1. Introduction

As one of the Overall Tedori Valley Developing Works, Electric Power Development Co., Ltd. and The Hokuriku Electric Power Co., Inc. developed the power generating work under their mutual cooperations. *Fig. 1* shows the outline of main stations and dams in the Tedori Valley and general specifications.

The 1st and 2nd PSs are AFC-operated from the Power Supply Control Center, and power generating schedule for the 3rd PS is established based on a telephone communication for the AFC-operation.



*1 : Electric Power Development Co., Ltd.
*2 : The Hokuriku Electric Power Co., Inc.

Item	1st PS (*1)	2nd PS (*2)	3rd PS (*2)
Type of power generation	Dam water channel	Dam water channel	Dam water channel
Maximum output (kW)	250,000	87,000	30,000
Effective head (m)	162.5	96	50
Maximum volume of used water (m^3/s)	180	105	70
Annually generated power (milion kWh)	459	274	151
	Tedori valley (*1)	Tedori 2nd dam (*2)	Tedori 3rd dam (*2)
Type of dam	Rock fill	Concrete gravity	Concrete gravity
Dam height (m)	153	37.5	50
Total pondage (million m^3)	231	2.1	4.4
Full water level (altitude m)	465	286	170
Effective pondage (million m^3)	190	1.7	3.2

Fig. 1 Outline of main stations and dams in the Tedori valley

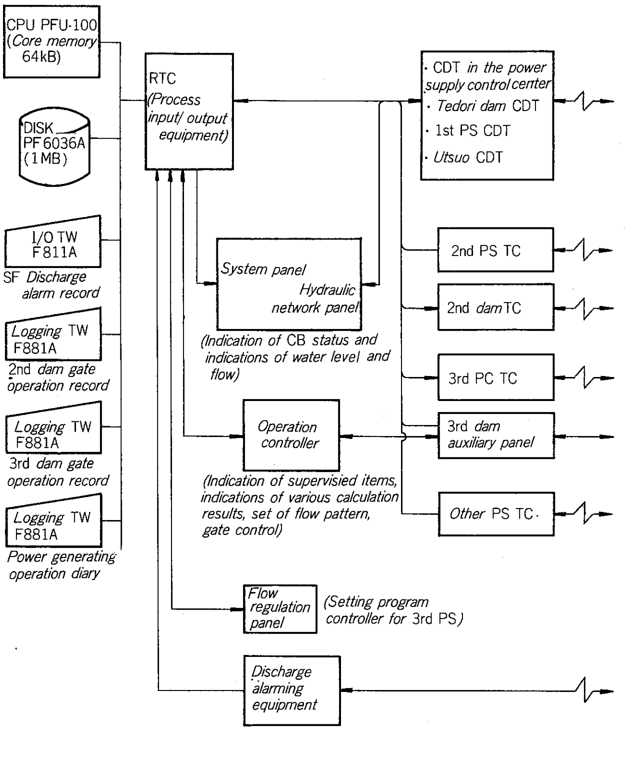


Fig. 2 System configuration

Table 1 Functions

Item	Object
Input processing	• Supervising input data • Smoothing processing (water level) • Mean value processing (MW) • Input lock processing, alternate data setting
Supervision	• Water level upper/lower levels • Flood • Discharge limit over • Swing of a dam water level • Down stream water level fluctuation • Noneffective discharge • Flow insufficiency
Control	• Predetermined water level discharge • Predetermined flow discharge • Preliminary discharge • 3rd PS flow regulation, adverse regulation
Recording and others	• Gate operation record • Flood record • SF print • Power generating operation diary • Power supply control center, Tedori valley dam data transmissions • Discharge alarm record • Constant change

The computer control system has been installed in the Control Center in the 3rd dam. This computer system is to supervise high dams in three locations, control discharges from flood discharge gates, record data for gate discharge controls, regulate water flow by the use of program controller located in the 3rd PS, operate adverse regulation automatically, and to record operations of ten power stations surrounding the hydraulic network. This computer system has already been used for the actual operations.

2. System Configuration

The computer system has been coupled with each dam and station through telecon basically in the manner of 1:1 as shown in *Fig. 2*, and data is taken into the computer through a relay contact with some exceptions. For the 3rd dam, the computer is directly coupled from the auxiliary panel, and CDT coupling is made for Tedori Valley Dam, 1st PS, etc.

3. Functions of System

Table 1 indicates functions of the system, and the system mainly functions to control and operate 2nd and 3rd dams.

The main functions, namely water level control and flow regulation of 3rd PS are introduced below.

1) Water level control

When an increase of water flowed into the 2nd and 3rd dams of Tedori Valley is presumed, level of water is lowered to the preliminarily reduced water level by a preliminary discharge by the following control method so that the predetermined water level is always maintained.

The water level at the time when predetermined water level control is started is used as the objective water level (H_0), water level (after smoothing) is supervised every one minute, objective discharge volume is calculated by the equations shown below when the water level exceeds HH ($H_0 + h$) or lowers below HL ($H_0 - h$), and by allocating gates, an operation request is output. (It is, however, within the limited volume.)

Gates are controlled by the operation request, the water level at the time when gate opening satisfied the objective opening is stored into the memory as the last time water level, the time elapsed thereafter is counted initially, and thus, water level is supervised. Thereafter, when a predetermined time is elapsed but the water level does not enter or exceeds the band as shown in *Fig. 3*, calculations are made again and an operation request is output again.

(1) Cases 1 and 1′

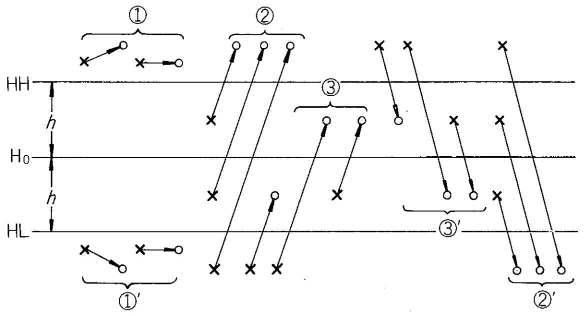
When a predetermined time has elapsed but the water level has deviated the band and it does not return to the band.

$Q = KQ_1$ *(In case of 1′ :* KQ_2)

(2) Cases 2, 3, 2′ and 3′

When water level exceeds the band between the last value and present value

$$Q = \frac{V(H_1 - H_2)}{T} \times KA_1 \text{ through } KA_4$$



H_0 : Objective water level
h : Water level control band (changed depending upon volume of water flowed into the dam)
× : Last time water level (after operating gate)
o : Present water level (when a predetermined time is elapsed or in case of a band-over)

Fig. 3 **Water level control method**

where, Q : Volume of water increased or reduced by discharging water from gate (m^3/sec)

$V(H_1 - H_2)$: Pontage increased or reduced from the last water level to the present water level (m^3)

T : Time required in reaching the present water level from the last water level (sec)

KQ_1 (KQ_6) : Volume of water discharged for the increase or reduction (m^3/sec)

KA_1 through KA_4 : Coefficient $1.0 < KAi \leqq 3.0$ (i = 1 through 4).

2) Flow regulating operation

Flow set value by every 30 minutes (by pin board) is read into the system from the flow regulating panel, and volume of water used by the Tedori 3rd PS is automatically regulated in compliance with the read value. (Flow regulator is used.) When the flow at the downstream measuring point (Nakajima) tends to increase, volume of water used by the same PS is regulated automatically based on the present flow at that point, and thus, volume of water reserved in the 3rd dam is used effectively. (Adverse regulation is used.)

Discharge starting time is reversely calculated in accordance with the increasing or reducing limit at the downstream measuring point so that no rapid fluctuation occurs when changing set flow, and thus, volume of used water is regulated.

In the actual control operations, pulses are output from the CPU through telecon, and opening of the guide vane is controlled directly. (Control method using number of pulses; A locking system is employed so that the guide vane does not operate rapidly even if an abnormal pulse is output.)

IV. COMPUTER CONTROL SYSTEM OF NISHI-KADOHARA HYDRAULIC NETWORK CONTROL CENTER OF THE HOKURIKU ELECTRIC CO., INC.

1. Introduction

This computer system is installed in Nishi-Kadohara Control Center which comprehensively manages a group of power stations in the places where main stream of Kuzuryu River flows into the open field. The purpose of this computer system is to supervise the Nishi-Kadohara Control Center time-to-time. With this computer system, flood status at the upstream can be caught correctly, power generators are automatically and systematically operated based on the flow forecast in accordance with the flood status at the upstream, and thus, the hydraulic network is operated efficiently within a range not affecting the downstream. *Fig. 4* shows the hydraulic network and power generating system.

This system has already been operated practically, and during night-times, the system is operated with operator unattended.

2. System Configuration

The system configuration is outlined in *Fig. 5*. The computer system is coupled with each power station through a data exchanger using micro-processor. Further, a micro-processor is used for each route, a modem channel control and SP (Series Parallel converter) are formed on a sheet of printed circuit board, and the processing is made in the form of a firmware.

Supervisory control of each power station is conducted by the master equipment of already installed one-to-one telecon. For the supervision of the overall hydraulic network and man-machine interface of automatically scheduled generator operation, etc., a high density CRT (with light pen) of 4,000 characters is employed.

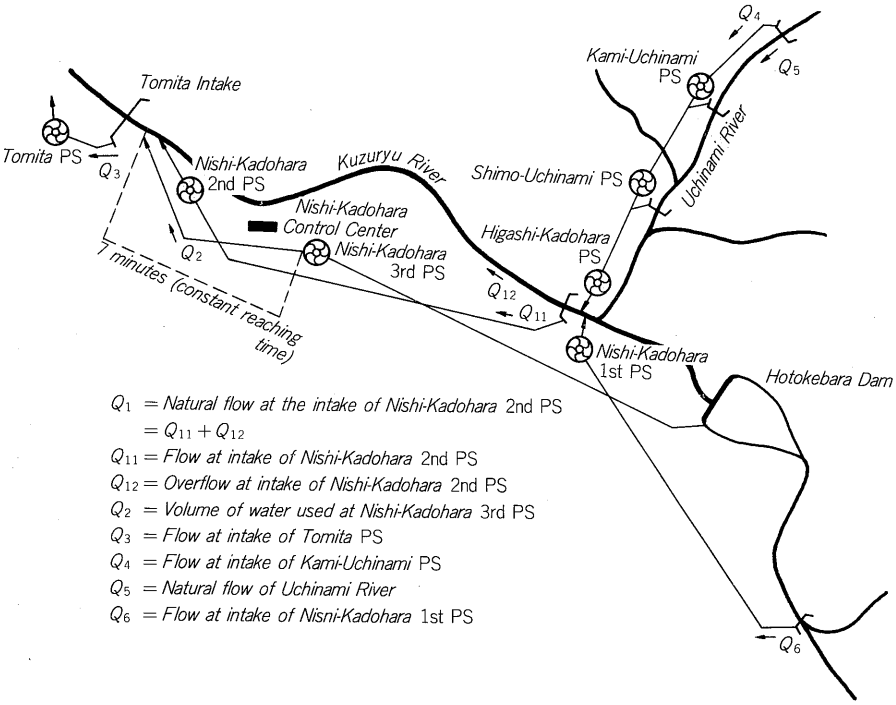
During night-times, no one attends the control center, and data are centrally displayed in the dormitory distanced about 200 meters from the Control Center. The data sent from each control station are edited by the associated data exchanger, directly transferred, and the alarm judged by the computer is output from the RTC (Process I/O equipment).

3. Functions of System

Table 2 shows functions of this system. Out of those shown in the *Table 2*, forecast of flow at Tomita intake, automatic power generating operation and maintenance functions using CRT are introduced below.

1) Forecast of flow at Tomita Intake

This hydraulic network consists of a group of power stations to each one of which water flows individually and Nishi-Kadohara 3rd PS which has mountain streams and regulating reservoir called Hotokebara Dam, and water from all of these places is finally collected into the intake of Tomita PS. To prevent water over-flowing the dam of this intake, other flow fluctuations must be absorbed by a regu-



Name of PS	Licensed output (kW)	Max. Volume of used water (m^3/s)
Kami-Uchinami PS	10,200	8.3
Shimo-Uchiname PS	4,500	6.71
Higashi-Kadohara PS	2.610	8.60
Nishi-Kadohara 1st PS	10,000	11.13
Nishi-Kadohara 2nd PS	7,200	26.41
Nishi-Kadohara 3rd PS	48,000	56.0
Tomita PS	19,200	80.0

Fig. 4 Outline of main stations and dams in the Kuzuryu valley

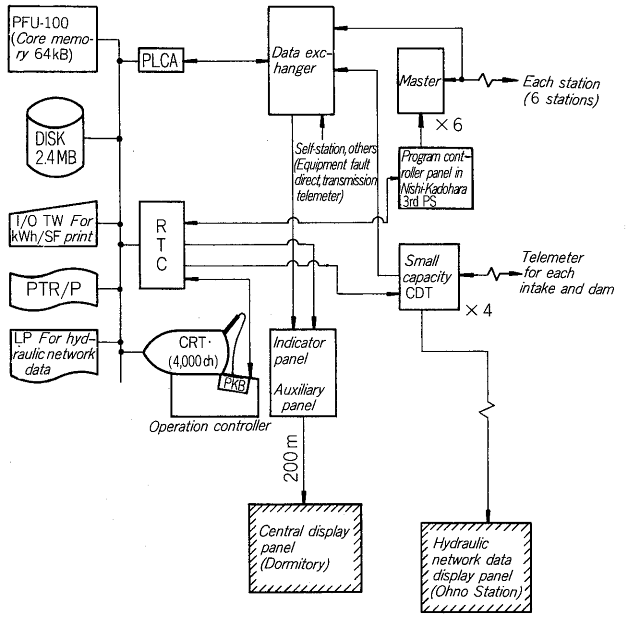


Fig. 5 System configuration

Table 2 Functions

Item	Object
Input processing	◦ Supervision of input data ◦ Smoothing processing ◦ Input lock, data set change
Supervision	◦ Hydraulic network status display ◦ Forecast of overflow at Tomita Intake ◦ Central alarm at dormitory
Automatic operation	◦ Automatic operation of program controller at Nishi-Kadohara 3rd PS ◦ Natural flow operation at Nishi-Kadohara 3rd PS
Recording and others	◦ SF print of each PS, SS and dam ◦ WH recording of each PS and SS ◦ Hydraulic network status recording ◦ Data transfer for Ohno Station (hydraulic network data) ◦ Maintenenace

latory operation of the Nishi-Kadohara 3rd PS.

Regulating ability of the Tomita Intake is small, and for this reason, it is anticipated that control may not be completed timely by supervising water level fluctuation only as the result of a flow increase. Particularly for a flood fluctuation such as a sudden flood which increases and reduces rapidly, the conventional method was not capable of controlling the system. To cope with an occurrence like this, a new method was developed. With this method, flow at the optimum upstream point is found (calculated from water level), and flow is forecast depending upon how many minutes later the water reaches the Tomita Intake. Water reaching time differs depending upon the water flowing route (stream or water pipe) and the flow. Thus, actual measurements are conducted in advance, and the measured data are stored into the memory of computer in the form of a table.

Forecast flow at the Tomita Intake is obtained through the following procedure. (Refer to *Fig. 4*.)

(1) Natural flow at the Intake of Nishi-Kadohara 2nd PS is forecast based on the flows at intakes located in the upstream.

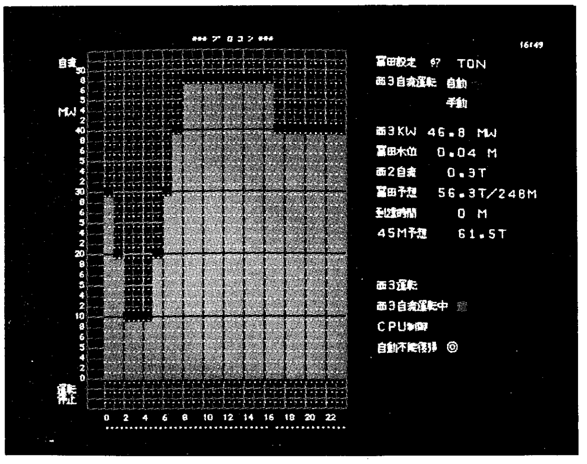


Fig. 6 Picture for program control

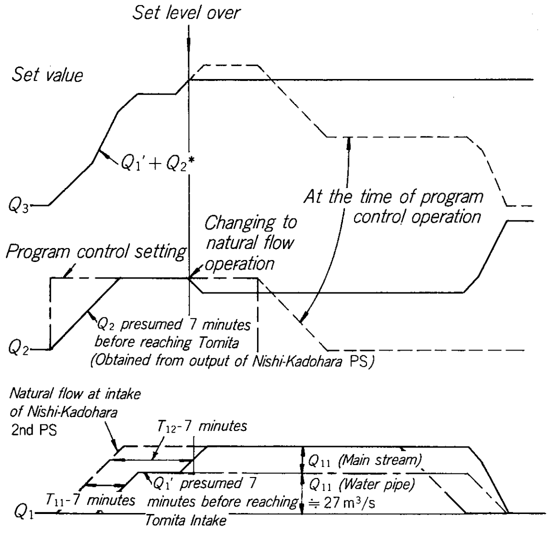


Fig. 7 Automatic changing time chart at natural flow operation

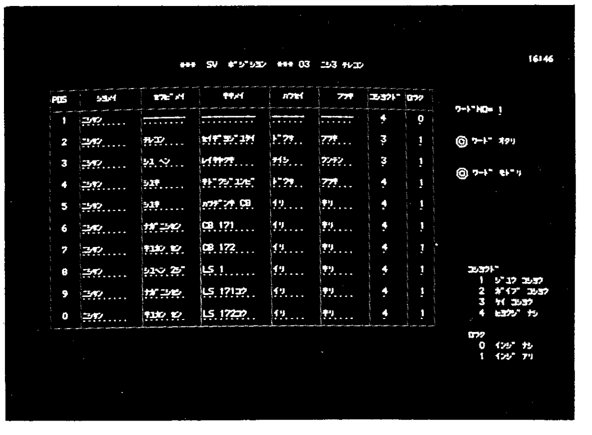


Fig. 8 Picture for maintenance

Flow of Q_4, Q_5 and Q_6 are obtained, the reaching times are obtained by referring to the conversion table, and in coordinating with the minimum value Tx, the natural flow Qx at the intake of Nishi-Kadohara 2nd PS at Tx minutes later is obtained.

(2) Flow at the Tomita Intake is forecast based on Qx.

Reaching time T_{11} of Nishi-Kadohara 3rd PS is obtained from Qx' by the use of conversion table, Tx is added, and time $T_3{}^*$ required in reaching from the upstream to Tomita Intake is obtained.

Flow $Q_3{}^*$ at the Tomita Intake at $T_3{}^*$ minutes later is obtained by the following equation.

$$Q_3{}^* = Qx' + Q_{12}{}^* + Q_2{}^*$$

In this case, Qx' is obtained with the present Q_{11}, Q_{12} as indicated below.

$Qx' = Q_{11}$ max when $Q_{12} = 0$, $Qx \geqq Q_{11}$ max
$Qx' = Qx$ when $Q_{12} = 0$, $Qx < Q_{11}$ max
$Qx' = Q_{11}$ when $Q_{12} > 0$, $Qx \geqq Q_{11}$
$Qx' = Qx$ when $Q_{12} > 0$, $Qx < Q_{11}$

$Q_{12}{}^*$ and $Q_2{}^*$ are flows at $T_3{}^*$ minutes later.

(3) $Q_3{}^*$ and $T_3{}^*$ are displayed in the program control picture on CRT (Refer to *Fig. 6*), and an alarm is output when an overflow occurs.

2) Automatic operation of Nishi-Kadohara 3rd PS

The functions are to automatically regulate output of Nishi-Kadohara 3rd PS in accordance with a program controlled operation schedule which is set on the CRT and to automatically regulate the same output so that flow at Tomita Intake is maintained in a constant value Q_3 (Set on CRT).

In the case of a natural flow operation, volume of water Q_2 used by the Nishi-Kadohara 3rd PS is automatically regulated so that the following equation is established.

$$Q_3 = Q_{11} + Q_{12} + Q_2$$

Further, regulation is made so that sum of the present value Q_2 and $Q_{11} + Q_{12}$ (value at 7 minutes later) is Q_3 because it takes 7 minutes to reach the Tomita Intake from the Nishi-Kadohara 3rd PS. Furthermore, the regulating width is multiplied with a reduction rate depending upon a water level at the Tomita Intake.

Even if the system is operated under the program control, when the flow exceeds Q_3, the operation can be switched over to natural flow operation, depending upon natural flow at the intake of Nishi-Kadohara 2nd PS. *Fig. 7* shows a time chart for this case.

3) Maintenance services by the use of CRT

Electric energy generating and distributing facilities and equipment are always expanded and modified in response to demand increase and system change. Consequently to the expansions and modifications, position configurations of telecon and pulse ratio of WH are changed frequently. The system introduced in this paper is capable of easily coping with the changes by making an access from the CRT.

Further, not only for the computer system but also the data exchanger which functions as an interface equipment

Table 3. Modifying functions with CRT

Item	Modified contents
SV position table	· Station name, equipment name, machine name, operation name · Degree of fault, printing lock
WH position table	· Position · Pulse ratio
TM position table	· Word · Unit of measure, absolute value/relative value, scale · Upper/lower limit values · Relative faulty position
Automatic power generating regulation	· Flow conversion table (Water level-Flow-Reaching time) · Reduction coefficient at Tomita Intake · Set upper/lower limit values, others.

of telecon, the system control status can be modified simply by making an access from the CRT.

Particularly, in this system, various constants for actual operations must always be adjusted to allow the automatic power generation control displaying the optimum ability, and with the data display and modifications of constant values by using CRT, this system can easily operate.

Table 3 and *Fig. 8* show items which can be modified from the CRT and examples.

V. COMPUTER CONTROL SYSTEM IN ARIMINE-JOHGANJI HYDRAULIC NETWORK CONTROL CENTER OF THE HOKURIKU ELECTRIC POWER CO., INC.

1. Introduction

The redevelopment plan for Arimine-Johganji Valley Hydraulic Network is mainly to generate power (about 400 MW) by switching over the water in Arimine dam from the conventional power stations in Wada Valley (about 200 MW) to Arimine 1st and 2nd PSs (newly built to cope with the peak load) and Arimine 3rd PS (for regulation) as shown in *Fig. 9*.

Arimine 1st and 2nd PSs are AFC-operated by the instructions sent from the Power Supply Control Center, the fluctuation component is absorbed by a newly built Oguchigawa dam, and the water is discharged into the Omata dam by the regulatory operations of Arimine 3rd PS. The effective pondage of Omata dam is only 590 thousand cubic meters, and for this reason, it is important to regulate power generating schedule by carefully examining status of both Oguchigawa and Omata dams so that no water will be discharged non-effectively even if water increases naturally by a rainfall in the area of Oguchigawa hydraulic network.

Further, the most suitable and correct judgement is required and actions must be taken timely without any delay when a flood occurs because the water which primarily flows into Wada hydraulic network is discharged into the Oguchigawa network by greatly changing the flow.

The purposes of this computer system are to utilize water efficiently by centrally managing the mutually relative five high dams and 18 power stations and to minimize a rapid change to the downstreams (this system will be started to operate during May, 1981).

2. Features of System

(1) For Oguchigawa and Omata dams which are most significant portions of the network, back up systems using micro-processor (FUJI MICREX-E) are employed so that they can be continuously operated even if the CPU system is down, and high reliability are secured efficiently.

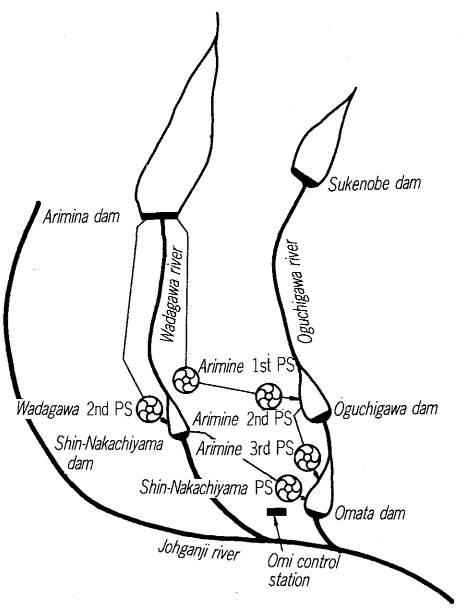


Fig. 9 Outline of main stations and dams in the Arimine-Johganjigawa valley

Item	Wadagawa 2nd PS	Shin-Nakachiyama PS	Arimine 1st PS (Newly built)	Arimine 2nd PS (Newly built)	Arimine 3rd PS (Newly built)
Type of power generation	Dam water channel			Water channel	Dam water channel
Maximum output (kW)	122,000	73,000	260,000	120,000	20,000
Effective head (m)	458.4	259.3	400	184	92
Maximum volume of water used (m^3/s)	32.2	33	76	76	26

Item	Arimine dam	Shin-Nakachiyama dam	Sukenobe dam (Newly built)	Oguchgawa dam	Omata dam
Type of dam	Concrete gravity				
Dam height (m)	140	45.5	35	79	37
Full water level (Altitude m)	1,089.5	604.0	1406.9	437.0	330.3
Effective pondage (million m^3)	204.4	0.07	8.75	1.5	0.59

(2) The system is joined with each dam through a telecon, and the computer in the system is coupled with a data exchanger using micro-processor. Also with the already installed telecons for power stations of different types, data are fetched from modem channels, and with the software processing of the data exchanger, difference of the interface is absorbed.
(3) Displays to the system panel, hydraulic network panel, fault indication panel and operation controller are made directly from this data exchanger, completely eliminating a blind even if the computer fails. Further, with employment of LED display and flicker processing by means of a software, all the systems consist of static elements, being provided with a high reliability.
(4) Particularly, the data exchanger for Omata dam is made to a completely duplex system because it takes an important position in composing the system.

3. System Configuration

This computer system is installed in Omi Control center which was built already before starting this project, and as shown in *Fig. 10*, this system supervises and controls the overall hydraulic network centrally.

The computer system communicates to the data exchanger in a high speed (450 kB/sec., maximum) by the use of PLCA (Parallel Line Communication Adapter).

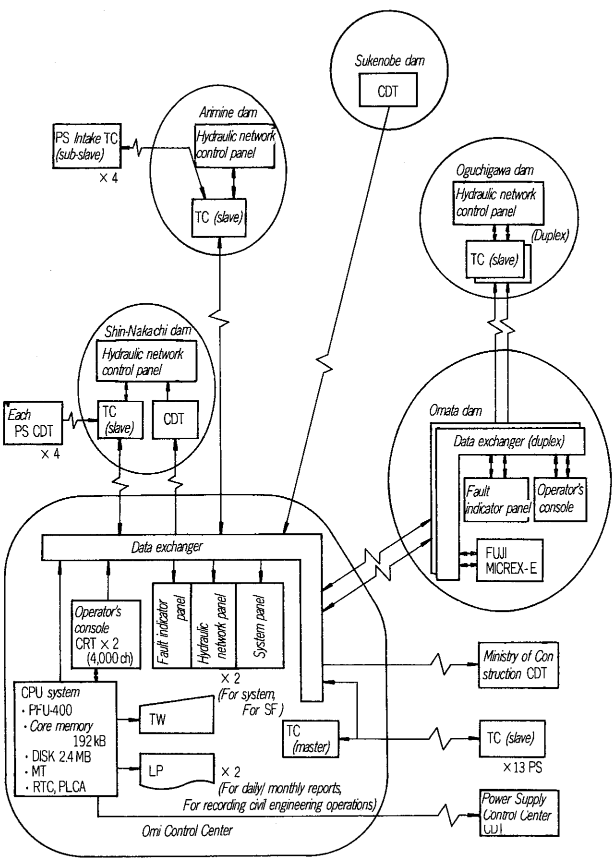


Fig. 10 System configuration

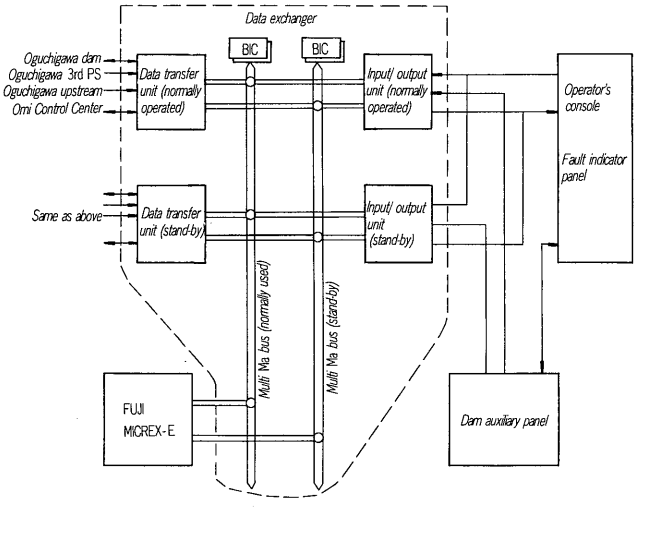


Fig. 11 Construction of duplex system of data exchanger

For operations of flood discharge gates, one-to-one operator's console is provided for every dams, and for other purposes, operations can be made easily by using the light pen of the high density CRT (4,000 characters).

To improve gate operating performance, each dam is equipped with a semi-automatic equipment, and with this equipment, each gate can be opened automatically to the objective opening by depressing the start button to output an instruction.

As for places where gates are operated actually, in Arimine dam, the gates are directly operated at the site only. For Omata and Oguchigawa dams, the gates are operated at Omata dam, and for Shin-Nakachiyama dam, the gates are operated at Omi Control Center. (For a while, gates a operated directly at the sites also for Oguchigawa and Shin-Nakachiyama dams, and for Sukenobe dam, instructions are given only.)

Because of the reasons as mentioned above, operator's consoles for Oguchigawa and Omata dams are located in Omata dam, and each dam is equipped with a panel directly.

The duplex system of the data exchanger in Omata dam is of a complex type as shown in *Fig. 11*, and a desired combination can be made among the individual units.

4. Functions of System

Table 4 shows functions of the system.

Out of those shown in *Table 4*, those backed up with FUJI MICREX-E are input processing and supervision for Omata dam and discharge control. (Object discharge volume is calculated only, and no gate allocation is made.)

The discharge control and CRT operation are described below.

1) Discharge control

(1) Discharge pattern

Opening of flood discharge gate is controlled by selecting one of the discharge patterns shown below for each dam on the CRT display.

Table 4 Functions

Item	Object
Input processing	· Supervision of input data · Smoothing processing (Water level) · Mean value processing (MW) · Input lock procssing, alternative data setting
Supervision	· Water level upper/lower limits, rising and lowering · Flood · Discharge limit over · Automatic limit discharge Flow over · Less than total discharge flow volume · Power generation stop in Arimine network · Stop of Arimine intake, Magawa pouring, and Totani pouring · Other equipment fault
Control	· Preliminary/initial discharge · Time delayed discharge · Water level control discharge · Flow control discharge · Natural flow discharge · Automatic discharge in case of flood (Arimine dam) · Intake gate · Program control (Arimine 3rd PS, Oguchigawa 3rd PS)
Recording, and others	· Gate operation record · SF print · Power generating operation diary, monthly report · Dam operation diary · Civil engineering operation diary, monthly report · Power supply control center, ministry of Construction data transmissions · Maintenance · Simulation

① Preliminary. Initial discharge: Water level of the dam is lowered by increasing discharge volume every 10 minutes in accordance with three types of discharge limit curve.

② Water level control discharge: The water level at the time when water level control operation is started is used as the objective water level, and level of water is controlled by observing water level changing speed so that water level is within the band width.

③ Flow control discharge: Discharge is controlled in accordance with the limited discharge volume so that discharged water volume is the set volume, and thereafter, discharging is controlled so that a predetermined value is maintained.

④ Natural flow discharge: For Oguchigawa and Omata dams, the natural flow into the dams (volume of water directly flowed into the dams) is discharged as an objective discharged volume. For this discharge, there are two patterns; one of them includes power generating discharge volume and the other does not include it.

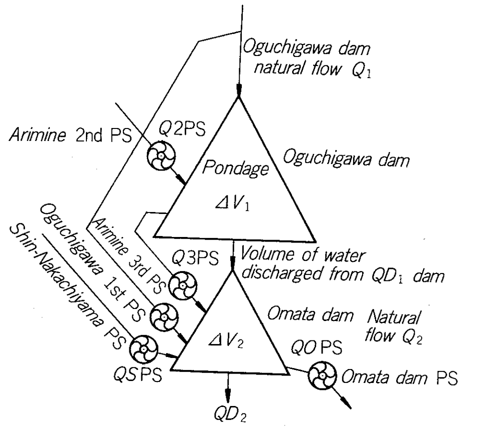


Fig. 12 Flow diagram in the Oguchigawa-Omata valley

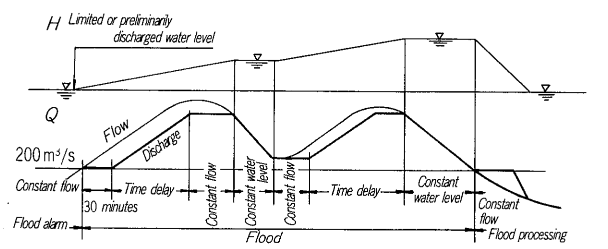


Fig. 13 Automatic operation pattern of discharge at flood

The natural flow of each dam (Volume of water directly flowed into the dam = Total volume of water flowed into the dam - Volume of water flowed into the dam indirectly) is calculated by the following equation. (Refer to *Fig. 12*)

Oguchigawa dam natural flow $(Q_1) = \Delta V_1 + QD_1 + Q3PS - Q2PS$

where, ΔV_1 is a mean value for n minutes of $\frac{V(H) - V(H')}{n \times 60}$ [$V(H)$ represents pondage curve], and for each discharge volume, mean value for 10 minutes is taken.

Omata dam natural flow $(Q_2) = \Delta V_2 + QD_2 + QOPS - (QSPS + QD_1 + Q3PS - Q1)$

⑤ Automatic discharge in case of a flood: For Arimine dam, in case of a flood, discharge pattern is automatically switched over by the computer as shown in *Fig. 13*, and thus, discharge is controlled. The term "Time delayed discharge" denotes a discharge for which a volume of water obtained by subtracting volume of water discharged for power generation from the volume of water flowed into the dam 30 minutes before the occurrence of flood (volume of water flowed into the dam is 200 m^3/sec. or more) is discharged as is.

(2) Flood discharge gate operation

An objective discharge volume is obtained in accordance with a discharge pattern, and the objective gate opening instruction is output in accordance with the gate operating sequence predetermined for each dam. When volume of discharged water does not reach the objective by operating one gate, operations of gates up to two gates are requested. When the operating mode is "Manual Mode", the operator selects a gate in accordance with the request, and operates the gate by depressing UP or DOWN push-button. When the operation is under semi-automatic mode, the operator depresses "Operation OK" push-button. Then, the gate is operated automatically to the objective gate opening by the semi-automatic system.

When the objective gate opening instructed from the computer differs from the present opening by a predetermined value or more, the semi-automatic system locks it as an "Excessive tolerance".

The semi-automatic system is of a duplex construction, and when a fault occurs, the normally operated system is automatically switched over to the stand-by system.

Various countermeasures are taken also for gate trouble, faulty telecon, faulty water level meter, faulty gate opening meter, etc.

In addition, a timer is installed in the machine side panel of the gate so that the gate operating system stops automatically when gate up/down signals continue for a predetermined time. Further, safety countermeasure has been adopted so that power supply of the machine side panel can be turned off forcedly from a remote place by depressing the emergency stop button.

2) CRT operation

(1) On-line data indication and set

A telemeter value input by each dam is indicated and updated every 10 seconds as is. When a difference between the present value and last value exceeds a predetermined value (successively in n times), an input lock applies automatically (The present value is held.), and red light flickers. With the red light, an operator can change hold value by the CRT.

(2) Calculated data indication and set

Results of various calculations are indicated and updated every 30 seconds for each dam. It is also possible to set this value.

(3) Past data indication

For each dam, volume of rainfall, dam water level, volume of water flowed into the dam and volume of water discharged from the regulatory reservoir for the period of the past five hours plus future one hour are indicated and updated every five minutes on a graph.

(4) Presumed volume of water flowed into the dam

For each dam, volume of water to be flowed into the dam m minutes later is forecast by the following equation every 2 minutes, and the forecast is indicated and updated on a graph.

$$Q_f = \frac{m+n}{n} \cdot (Q_r - Q_o) + Q_o$$

where, Q_f: Forecast volume of water to be flowed in
Q_r: Volume of water presently flowed-in
Q_o: Volume of water flowed-in n minute before

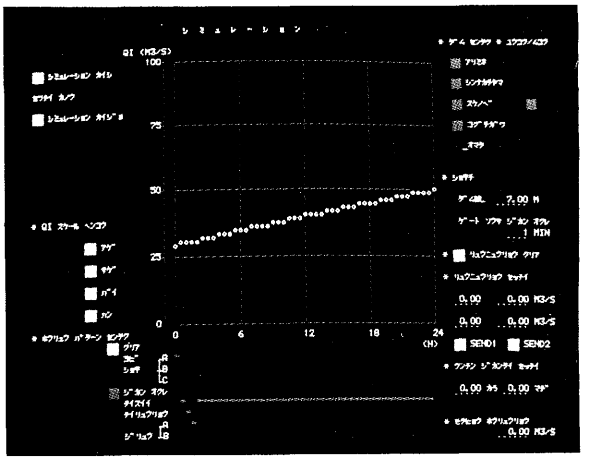


Fig. 14 Picture for simulation

(5) Discharge pattern indication and set

Each discharge pattern is selected. In case of a water level control discharge, water level at the time when the discharge was started is indicated, and in case of a flow control discharge, flow is set by the CRT.

(6) Control

The water intake gate of Arimine dam, flood discharge gate of Shin-Nakachiyama dam, and others are controlled by the CRT.

(7) Indication and set of program control operations

For Arimine 3rd PS and Oguchigawa 3rd PS, volume of water discharged for power generation is automatically regulated in accordance with the operation schedule previously set by the CRT with a telephone communication from the Power Supply Control Center. Arimine 3rd PS is set with a flow, the set value is converted to MW, and the converted MW is output to the sequencer in the site.

(8) Indication of immediately reported data

Based on the dam operating regulations, water level of the dam, volume of discharged water, volume of water flowed into the dam and time at each warning stage (in case of a flood) are indicated by each dam. Time-to-time reports for flow and volume of rainfall within the area of Toyama electric power supply system are indicated.

(9) Gate operation recording

For each dam, gate operating record is indicated for one day. At 24:00, or whenever required, gate operation record can be output to the line printer. A gate operation within 1 minute is handled as a continuous operation.

(10) Operation diary

Data regarding power generating operations and civil engineering work are indicated for that day and yesterday. Further, the data can be corrected by the CRT.

(11) Maintenance

Individually monitored upper/lower limits and cycles, constants required for control operations, coefficient of curve for capacity of reservoir and time are set and changed.

(12) Simulation of discharge control

A pattern of volume of water flowed into a dam is presumed, and it is set by the CRT. (Refer to *Fig. 14.*) Further, discharge pattern is set also on this CRT screen. When start of a simulation is ordered, water level is calculated inversely in response to a set volume of water flowed into the dam, and input area of water level meter is updated. Next, the objective volume of water to be discharged is calculated and allocations of gate opening are made in accordance with the discharge pattern. (In this case, gate is not operated, but gate opening is updated by means of a program as if the gate was actually operated.) Thus, volume of water to be discharged is calculated and water level is inversely calculated once again by obtaining volume of water to be reserved from the difference against volume of water flowed into the dam. Simulations are made by repeating the above calculations.

As for the computer processings, calculation of every 30 seconds is carried out normally, and simulation is made by shortening the time axis. Hence, operations for 24 hours can be simulated within about 3 hours.

VI. POSTSCRIPT

It is said "Water is a treasure, and at the same time, it is a living thing". We feel, it means the use and control of water are difficult that much. As seen in the actual examples introduced in this paper, the area of a hydraulic network control is increasing more and more, and an aid of computer is extremely useful to operate multiple number of dams and power stations comprehensively. On the other hand, however, systems in various supervisory control functions, constants used for the systems, etc. have not been firmly established yet. And, we can say the existing or future hydraulic network control systems have many phases that must be further improved through accumulations of data based on the actual operations, simulations of total network with mutual relationships among the individual dams taken into consideration, etc.

Closing this paper, we should like to express our deepest appreciations to those who gave us valuable instructions and advice in designing and manufacturing each one of the systems introduced in this paper.