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CONTACTLESS CONTROL DEVICE FOR JOGANJI-GAWA NOS. 2, 3 & 4 POWER STATIONS, HOKURIKU ELECTRIC POWER CO., INC.

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I. PREFACE

The advancement in the field of all kinds of highly efficient semiconductor elements is making static and contactless power apparatus and protective relaying equipment increasingly popular.

A growing emphasis has been placed by our company upon the development and manufactures of all sorts of stable logical elements and protection relays. In February, 1961, we delivered for the first time as a power protective device a system detaching relaying device to Seki Switching Station of Kansai Electric Power Co., Inc. at which time it was proven that out-of-step phenomena could be controlled by the utilization of semiconductors such as transistors, for example. On the strength of this successful precedence, other companies followed suit with their preference for our equipment. In October, 1962, furthermore, we delivered to the direct grounding system in the Nahari Main Line 180 kv of the Eletric Power Development Corporation a directional distance comparison blocking type carrier relaying device, thereby crowning the role as the pioneer in the development of contactless protective relaying equipment.

Research has also been continued, in the meantime, in the area of contactless control devices and we have recently installed an operating system with all contactless equipment at Joganjigawa Nos. 2, 3, and 4 power stations of Hokuriku Electric Power Co., Inc. The equipment went into commercial operation as of the middle of March, 1964.

The following chapters describe these control devices.

II. OUTLINE OF OPERATING SYSTEM

These new power stations are situated in the lower reaches of the Joganji river (Joganjigawa), in the downstream from the No. 1 power station which was previously established. The No. 2 Joganjigawa Power Station derives water from the Arimine reservoir which releases volume in a seasonally adjusted manner on the one hand, and from the mainstream of Joganji river on the other. This water supply is then led to the Nos. 3 and 4 power stations in that order. Along with their characteristics as underground power stations set up on plain soil, the capacity of 5,340 kw, the biggest as a tubular turbine, is noteworthy. The main apparatus of each power station is designed accoding to the same rating.

Since this group of power stations is located at the lower most reaches of the Joganji river, there is an affluence of water throughout the year which may be turned on for hydrogeneration and it is expected that these stations will furnish stable electric power supply at all times.

These stations are, at the same time, situated in areas where crops are grown and part of the same water is used for agricultural purposes. Consequently, there are relatively severe restraints in regard to the utilization of this waterway.

The system of operating these stations is an occasional supervisory system consisting principally of fully automatic operation according to the amount or volume of water flow. The main duty of an operator is to maintain the stations in good running order and he stays on the alert only during the day, the stations being subjected to fully unattended operation during the night.

The headquarters of these three power stations is located at the No. 3 power station and the conditions of Nos. 2 and 4 are relayed to the No. 3 station by means of telecontrol, so that it is possible to supervise the conditions of Nos. 2 and 4 stations from the No. 3 station.

III. SYSTEM OF CONTROL

Nos. 2 and 4 power stations are connected to the No. 3 station by means of a 20 kv transmission line from which it is hooked up to all 20 kv systems. At each power station, the operation may be either one-man control or fully automatic.

1. One-man Control

This is a one-man control in the usual connotation of the word in which the master switch is operated to perform various functions according to the respective positions of this master switch.

At load position, it is possible to control the equipment manually as well as by means of a water level governor so that the equipment may be subjected to load conditions commensurate with the water level obtaining at that time.

2. Fully Automatic Control

When the master switch is at the no-man position, the lower power station may be started or stopped in accordance with the water level at the upper water resarvoir and in accordance also with the starting or stopping of the upper station. In other words, when the upper station starts operating, this fact is immediately conveyed to the lower station by means of telecontrol and the lower station, in turn, ascertains that the water level is above the minimum requirement for commencement of operation on the basis of the communication from the upper station. At this time, the lower station renders the equipment ready for operation and, upon completion of the preparatory work, the equipment starts working automatically and goes through the envisioned sequence and when the cycles are stabilized and voltage established an automatic synchronizer gets activated to become automatically parallel. After this phase, a water level governing circuit is automatically created to generate electric power in accordance with the volume of water flow-in.

When, on the other hand, the water volume is reduced and the output decreases to the point of no-load opening by order of using the water level governor almost takes place, advantage may be taken of the continuation of low load conditions for a certain length of time in order to trip the solenoid valve for a turbine start and stops, to operate the turbine in the stop direction and open a parallel switch to stop it.

When the turbine stops, the water level governing circuit is switched over to bypath gate control and continues to keep the water level of upper reservoir at a certain level.

Control devices for these power stations with the identical rating for all three, therefore, are required to meet the conditions of simplified control circuits by reason of using no-man operation, of trouble-free running and of stabilized operation.

In consideration of these factors, transistorized contactless control systems are employed as control equipment at these power stations.

In addition to various kinds of logical elements already developed, the following devices are used, all contactless :

(1) Contactless limited switches
(2) Contactless operation, change-over switches and master switch
(3) Automatic speed matching equipment using static relaying principles (♯ 15)
(4) Contactless automatic synchronizer (♯ 25)
(5) Contactless three point regulator (for control of water level, etc).
(6) Contactless control equipment of servomotors (e.g. governor motor, load limit motor, etc).

For the power source of transistorized control equipment, a constant voltage dc-ac inverter system using SCR is employed.

These devices are organically combined according to the logical element to take care of starting and stopping the power station.

IV. ABOUT DEVICES

1. Contactless Limit Switches

The contactless limit switch is characterized by superior features such as :

1) No arc develops at the time of opening and closing, which means the absence of contact wear ; what is more, inflammables and metallic materials nearby are not seriously affected.

2) There cannot be any malfunction even in the worst environment.

3) Neither maintenance nor inspection is necessary.

The electrical output of a limit switch may be very small when it is intended to be used as one of the elements in the contactless device, so that its shape may be made small and the weight light and yet without the loss of sturdiness.

Fig. 1 shows the principle of the contactless limit switches used in the power stations under review. Both the primary winding and the secondary winding (output winding) are wound around a U-shaped iron core, and the use is made of changes in the induced electromotive force of the secondary winding arising out of drawing or rejecting another iron piece on the part of the opening section of the U-shaped iron core.

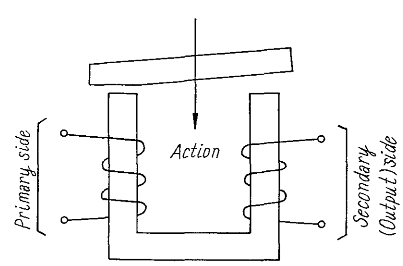


Fig. 1 Principle of contactless limit switch

2. Switches

Switches may be devided into the following :

1) Operating switches
2) Change-over switches
3) Master switches

Since one switch is required to open and close a number of circuits, it is composed of a required number of layers of switches. When it is intended for use in a multiple of circuits, its overall size is built more liberally to ensure certainty of operation and due consideration is also paid to making it as sturdy and endurable as possible.

As for contacts, there are a number of problems common to all contacts to which due consideration needs to be paid.

It is necessary that the switches for electric switch boards should be very endurable because of a comparatively high frequency with which they are operated. It is, on the other hand, both appropriate and necessary that they be at the same time small in size, light in weight and convenient in handling.

The contactless switches are, in the light of these viewpoints, the most ideal switches to meet these requirements.

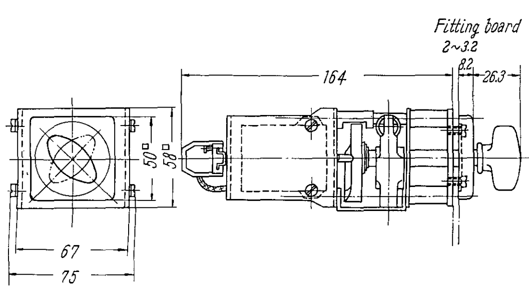
When these are combined with a contactless device, they are required to send only one signal per operation represented by that signal, the rest being controlled in various ways by the logical element within the device which is assigned to all kinds of circuits.

The present switch houses one element for one signal of operation and when it is operated the element functions to transmit an operational signal to the logical element circuit in the device.

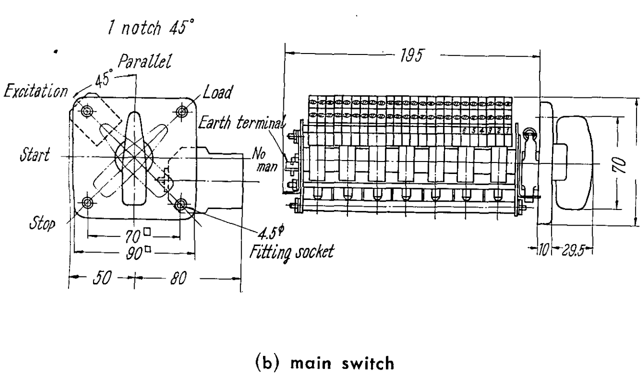
The element thus used is a normal type manufactured as a contactless limit switch.

As far as its performance goes, it is exactly the same as the contactless limit switch.

Fig. 2 shows an exterior view, respectively, of a two position change-over switch and a master switch.



(a) 2-point switch



(b) main switch

Fig. 2 Contactless switches

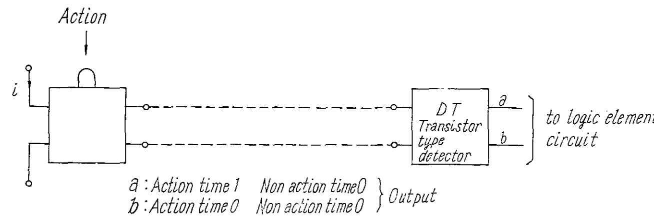


Fig. 3 Operating method of contactless switches

Fig. 3 represents the system of connection when a contactless switch is used.

3. Contactless Automatic Speed Matcher

One of the conditions of joining the generator parallelwise to a system is that the frequency of the generator and that of the system be identical.

This speed matcher gives instructions to operate a governor motor *65 M* in order to make the frequency of the generator identical to that of the system by judging a difference in both frequencies as well as speed variation on the part of the generator frequency.

The sequence is laid down by making use of the transistorized logical element so that the output of this device is a logical output of 1, 0.

The control time is varied according to the length of frequency and the speed is so controlled as to be equal to the frequency of the system, in consideration of the inertia constant of both turbine and generator.

The relationship between the control output signal and the frequency may be defined as follows:

1) When the absolute value of the frequency $|\Delta f|$ is higher than Δf_h, the instructions are continuous.

2) When $|f|$ is between Δf_h and Δf_e, the instructions are for a time of τ_1 for a frequency of one slip.

3) When the frequency still approaches the frequency of the system and $|\Delta f|$ becomes smaller than Δf_e, the instructions are for τ_1 sec. for a frequency of two slips (provided $0<\Delta f_e<\Delta f_h$).

In order to carry out this, it is necessary to have a circuit to detect speed variation in the turbine-generator frequency and a circuit to judge the length of frequency.

Fig. 4 shows a vector diagram which illustrates

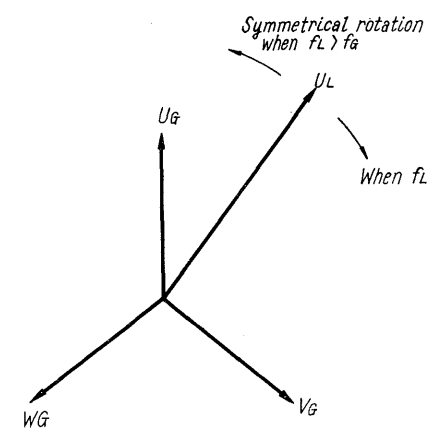


Fig. 4 Vector diagram of frequency comparison

graphically the principle of detecting the delay of system frequency f_L and generator frequency f_G.

In the diagram, vectors U_G, V_G and W_G represent voltages of the three phases of the motor, while vector U_L represents voltage of the single phase of the system. In case there is a frequency difference of Δf between f_G and f_L, the voltage vector U_L of the system, on the basis of generator voltage U_G, V_G and W_G, becomes:

when $f_L > f_G$ counterclockwise
when $f_L < f_G$ clockwise

and at the slip frequency of $T = 1|\ f|$ sec.

In other words, the system voltage U_L becomes identical with each phase voltage of the generator in the order of $U_G \rightarrow W_G \rightarrow V_G \rightarrow U_G$ in case $f_L > f_G$, and, in the order of $U_G \rightarrow V_G \rightarrow W_G \rightarrow U_G$ when $f_L < f_G$. The lag then is $T/3$ sec.

Consequently, it is possible to detect and judge the delay between the system frequency and the generator frequency by the order of correspondence between the single phase voltage of the system and the phase of each voltage of the generator. It is equally possible by the time lag at the point of phase correspondence to judge the absolute value $|\Delta f|$ of the difference between the two.

Fig. 5 shows internal connections of this device (sequence diagram) and the output of FF_1 and FF_2 is controlled by P_1 or P_2 in accordance with the judgment referred to above. The circuits in between are auxiliary circuits to take care of the controls referred to under 1) through 3).

Output from P_1 or P_2 may be directly obtained from the transistor so that the circuit to drive *65 M* is governed by an SCR circuit to be dealt with later. Even the minutest output may be transmitted without fail, thus making smooth control possible.

Specifications of this device are as follows:

Δf_h: 3~6 (c/s) continuous adjustment possible (110~220 m sec. in terms of τ_1)
Δf_1: 0.5~3 (c/s) continuous adjustment possible (0.22~0.3 sec. in terms of τ_2)
τ_1: 110~220 m sec. continuous adjustment possible

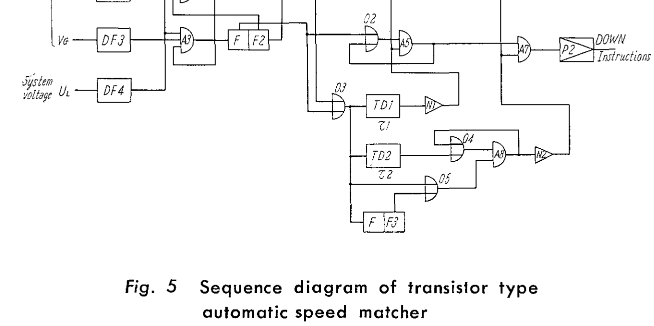


Fig. 5 Sequence diagram of transistor type automatic speed matcher

4. Contactless Automatic Synchronous Closing Device

To join the generator which has already started to the system without any shock it is necessary that at the time of parallel joining the frequency and phase be in correspondence and it is desirable that the voltage be also in harmony.

The present device gives making instructions in advance of the required time corresponding to the time from the phase correspondence point of both systems to the making time of the making switch within the conditions under which both frequency difference between the two systems as well as voltage difference are held within certain values. Therefore, the device is composed of the following four sections:

1) A circuit (ΔT circuit) which gives a making instruction pulse, irrespective of the frequency difference, in advance by the amount of time equal to the duration from the point of phase matching to the making time ΔT of the making switch;

2) A circuit (frequency difference limiting circuit) which lets the output under 1) pass only when the frequency difference between the systems is within a certain value;

3) A circuit (voltage balance detecting circuit) to detect the voltage difference between the systems being below the predetermined value.

Specifications of this device are as follows:

$\Delta T = 0.2$ sec. (possible to manufacture between 0.1 and 0.5 sec).

$\Delta v = 2 \sim 6$ v (continuous adjustment possible)

Δf_0 (limiting frequencies = 0.25, 0.20, 0.15 c/s adjustable) making instructions continuing time = 1 sec.

5. Contactless 3-position Controller

When each device and control circuit is constructed by logical elements, it is at the present time rather difficult to make an automatic to manual switch-over circuit, etc. out of an analogue controller by making use of the output of several watts such as for electric power, to the exception of cases in which the output of an analogue controller is extremely small. Even if it is possible, it is bound to be very complex and costly.

When using a digital controller, on the other hand, it is possible to select any of the controls freely in combination with various interlocking conditions in the control circuit.

The controller used this time is of the digital system in consideration of these factors and by matching the control time to the time constant of the controlled systems, etc. speedy and appropriate control has become possible.

1) about 3-position controller

The controller used here is called a transistorized 3-position controller, of which output is provided by on-and-off functions of the transistor, or, a contactless intermittent controller, characterized by:

(1) Distance between on and off functions as well

as the dead zone may be freely changed. The dead zone may be narrowed down at ±0.5% at maximum sensitivity.

(2) It has a negative feed back circuit sufficient to secure stability even when the dead zone is narrowed, which forms a nonlinear stabilizing circuit which reduces deviation quickly when it is great (or large) and functions slowly for compensation when the deviation is small, along with the on and off function.

(3) By furnishing an additional element it is possible to set at will the duration in which the output is cut off in a kind of sampling control.

(4) The wholeunit is housed compactly in a box and together with the unit amplifier inside, the plug-in system is used for the convenience of upkeep.

2) Functions and performances of transistorized 3-point controller.

Functions of the transistorized 3-point controller differ according to whether or not there is an additional element as mentioned above. The first description will be of the standard type without any additional element. *Fig. 6* shows a block diagram in which the circuits are symmetrical on the plus and minus sides. A deviation input entering at left goes into the directly connected d-c amplifier A, is amplified and enters the skip characteristic amplifier B. These two amplifiers constitute the mainstay of this three point controller. *Fig. 7* shows the relation-

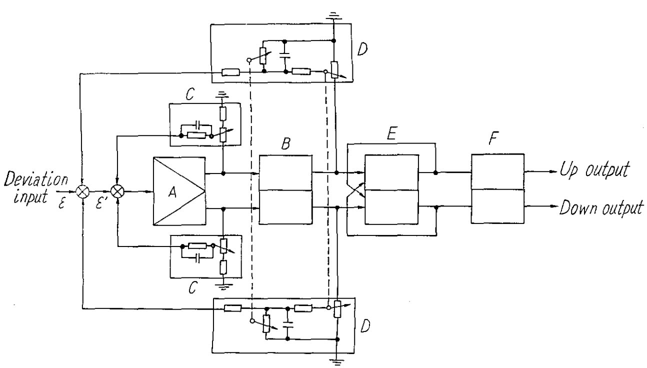


Fig. 6 Block diagram of three point controller

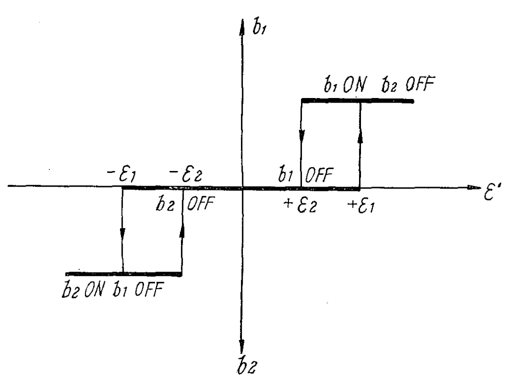


Fig. 7 Characteristic of amplifier

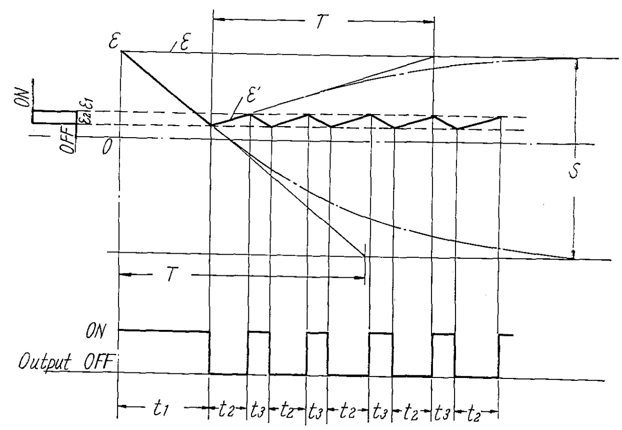


Fig. 8 Output response for step input

ship of the output of the skip characteristic amplifier to deviations. When the deviation is zero, the output of the skip characteristic amplifier is off but when the deviation increases and exceeds $+\varepsilon_1$, output b_1 turns on. When it decreases and becomes smaller than $+\varepsilon_2$, the output b_1 goes off, and in the case of reversed polarity in which it returns to the original state, it functions in the same manner. The condition of three points may thus be obtained by the deviation. The dead zone $\pm\varepsilon_1$ may be freely adjusted by changing the variable resistance in the dead zone adjusting circuit C. A condenser in this feed back circuit prevents the skip characteristic amplifier from functioning due to noise at the deviation input.

When the feed back circuit D is hooked up as it is at the output of the skip characteristic amplifier, it functions as a controller and the output of the skip characteristic amplifier in relation to step change ε of the deviation input is shown in *Fig. 8*. In other words, when a certain deviation ε exceeding ε_1 of the dead zone is in, the skip characteristic amplifier functions and the output is put on ; at the same time, the condenser of the feed back circuit D is charged and the exponential function of the negative feed back amount increases with the time and ε' decreases. After the lapse of time t_1, when ε' becomes smaller than ε_2, the output is cut off and at the same time the condenser of the feed back circuit D is discharged and the negative feed back amount decreases exponentially with the time while ε' increases. When, after the lapse of $(t_1+t_2)\varepsilon'$ becomes larger than ε_1, the output is again turned on, after which it repeats on and off operations. When the saturation value of output is defined as S (of the feed back circuit D), and the charge and discharge time constant as T, the following formula stands provided the first pulse, absence, and the next pulse are termed as t_1, t_2 and t_3, and that the filtering effect of the d-c amplification is neglected :

$$t_1 = -T\,ln\left(1 - \frac{\varepsilon - \varepsilon_2}{S}\right)$$

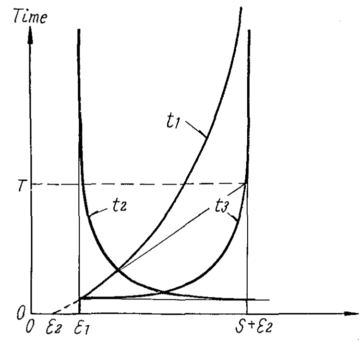


Fig. 9 1st and 2nd ON time, OFF time

$$t_2 = -T\,ln\left(\frac{\varepsilon-\varepsilon_1}{\varepsilon-\varepsilon_2}\right)$$

$$t_3 = -T\,ln\left(\frac{S-\varepsilon+\varepsilon_2}{S-\varepsilon+\varepsilon_1}\right)$$

Fig. 9 shows this in a graphic manner.

The output of the skip characteristic amplifier goes through an inhibitive circuit of E and lights up the output indicating lamp through the output amplifier F and transmits the output to the outside.

The controller shown in *Fig. 6* by means of a block diagram is used for a voltage adjusting device.

Fig. 10 also indicates a block diagram of a case in which a kind of sampling function takes place with the addition of an additional element to the basic type. As far as the d-c amplifier A, the skip characteristic amplifier B, the dead zone adjusting circuit C, the inhibitive circuit E and the output amplifier F are concerned, this is exactly the same as the basic type. Only, a timing circuit G is added to this basic type and a feed back circuit D is fitted outside (the feed back circuit inside is then out of service, being set to zero). Functions as they take place under these conditions are detailled in *Fig. 11*.

When a certain deviation ε enters which exceeds the dead zone ε_1, the skip characteristic amplifier goes on. The inhibitive circuit E is made out in such a manner that the output e_1 turns on only when the output b_1 of the skip characteristic amplifier is on, the timing circuit output g_1 is off and the output e_2 on the opposite side of the inhibitive circuit is off.

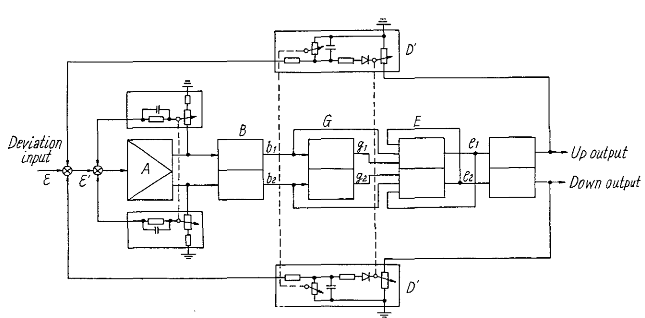


Fig. 10 Block diagram of three-point controller with timer

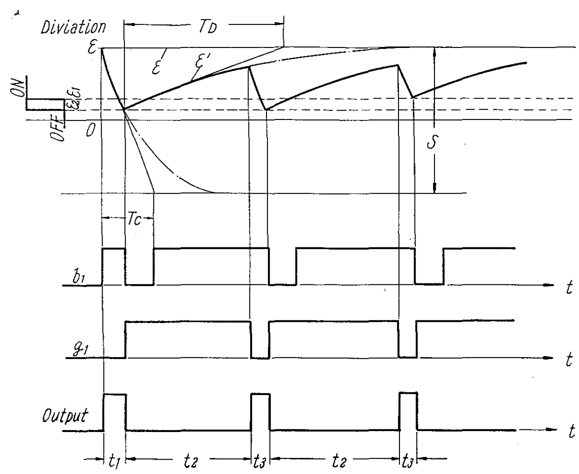


Fig. 11 Output response for step input

So when the skip characteristic amplifier is on, the above conditions are satisfied, which is reflected in the output. At the same time, there is a negative feed back which increases as an exponent function through the feed back circuit D' and as, after the lapse of time t_1, ε' becomes smaller than ε_2, the skip characteristic amplifier goes off and the output goes off also. On the other hand, the timing circuit G goes on the moment the output of the skip amplifier goes off, and, after the lapse of a certain duration t_2, it is designed to go off. Therefore, even if the feed back amounts decreases, ε' exceeds ε_1, and the skip characteristic amplifier goes on again, the output of the inhibitive circuit is not immediately influenced and only when the timing circuit goes off after the duration of t_2 seconds does it first appear at output. Again, the feed back increases, and the skip characteristic amplifier turns off and the output goes off also. Thereafter, the same phenomena repeat themselves. The feed back circuit D' has a diode, unlike D in *Fig. 6*, and the discharge duration is longer as compared with the charge duration of the condenser. When the saturation value of output of the feed back circuit is defined as S, the charge time constant, discharge time constant and timing as T_C, T_D, and T_T respectively, the first pulse duration, the absence duration and the next pulse duration t_1, t_2, and t_3, are the greater value of the following formula, provided the filtering effect of the d-c amplifier is disregarded, or, any of the greater value of:

$$t_1 = -T_C\,ln\left(1-\frac{\varepsilon-\varepsilon_2}{S}\right)$$

$$t_2 = T_T \quad \text{or} \quad -T_D\,ln\frac{\varepsilon-\varepsilon_1}{\varepsilon-\varepsilon_2}$$

$$t_3 = -T_C\,ln\left\{\frac{S-\varepsilon+\varepsilon_2}{S-(\varepsilon-\varepsilon_2)e^{-\frac{T_T}{T_D}}}\right\}$$

or

$$-T_C \, ln\left(\frac{S-\varepsilon+\varepsilon_2}{S-\varepsilon+\varepsilon_2}\right)$$

Fig. 12 diagrams this relationship.

The device as depicted in the block line in *Fig. 10* is used for a piece of water level governor control equipment.

These 3-point controllers are given the driving circuit of the relevant motors through transistor logical circuits. (In the case of water level control, they are connected to load limiter or motors driving the water gate). From the foregoing it may be clear that the response from the input of the controllers to the rotating position of the motor shaft performs a kind of proportional and integral function or action. Differently stated, it moves liberally at first (proportional action) against stepfunctional input and then moves slowly (integral action). (Refer to *Fig. 13*). The proportional action is determined by the first pulse duration, and the sensitivity is given in the following formula:

$$\text{Sensitivity} = t_1/\varepsilon$$

so that when the deviation is large, the relative sensitivity increases to act toward rapidly making the deviation small.

3) Construction of each unit amplifier and efficiency of controller

A, B, E, F and *G* shown in the block diagram are housed in the uniformly sized case, respectively. The d-c amplifier is a directly connected differential amplifier consisting of six transistors and it uses a silicon transistor in order to reduce temperature drift to a minimum. The skip characteristic amplifier uses a Schmidt circuit, while the output amplifier uses two steps collector earth circuit and the timing circuit is a single stabilized circuit. Switch-over by the condenser fitted to the panel and continuous variation of resistance may set the timing freely. In each case, one and the same circuit takes care of up and down functions.

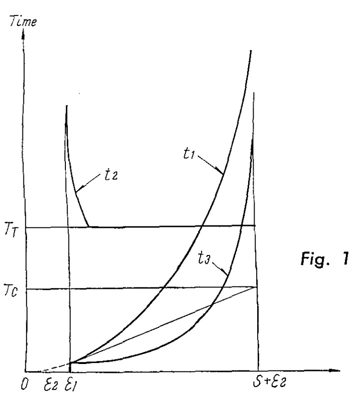


Fig. 12 1st and 2nd ON time, OFF time

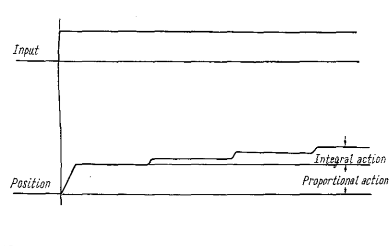


Fig. 13 Transient response from controller input to motor shaft

Performance specifications of the controller are:

(1) Input	D-c 10 v, input resistance 20 kΩ
(2) Output	D-c 24 v, 80 ma
(3) Output indication	By lamp for both up and down
(4) Dead zone	±0.5〜2.5%
(5) Internal feed back	Saturation 0〜40% Time constant 2〜2.4 sec
(6) Timing	4〜30 sec
(7) External feed back	Saturation 0〜50% Charge time constant 7〜70 sec Discharge time constant 20〜400 sec

4) Water level governor control (Level controller)

The present power station is a so-called flow in type power station which generates electricity in accordance with the volume of water flow-in. At the same time, there is the necessity to secure water at all times because the same waterway is drawn on for other utility water in the form of branching.

In order to keep the water level at a constant value, the level of water at the upper water reservoir must be kept constant for the waterway gate alone to control it by its opening.

For this, it is necessary to employ a water level constant system for controlling the water level.

Water level governing primarily consists in keeping the water level at a constant value. However, as it is difficult to secure stability of automatic control at hydroelectric power stations and as a slight lowering of the water level against the effective head is immaterial, often the system heretofore in use has been to carry loads in accordance with the water level.

However, at the present power stations, in addition to the fact that the water is being utilized for other purposes as well, the head is comparatively low and a slight decrease in the water level affects the output. Besides, the maintenance of the water level at a high value is desirable for high efficiency operation of the turbine. Therefore, at these stations, a water level constant system is employed.

The three power stations being connected in a series in this water system, it may happen that any of the stations for one reason or another has to be stopped, in which case also the water level of the upper reservior must be kept at a constant figure. It is for this purpose that the circuit may be switched automatically, when water level control governed by the turbine stops, in such a manner that the instructions are for the surge tank bypath gate to operate the opening and closing of the bypath gate to keep the water level constant.

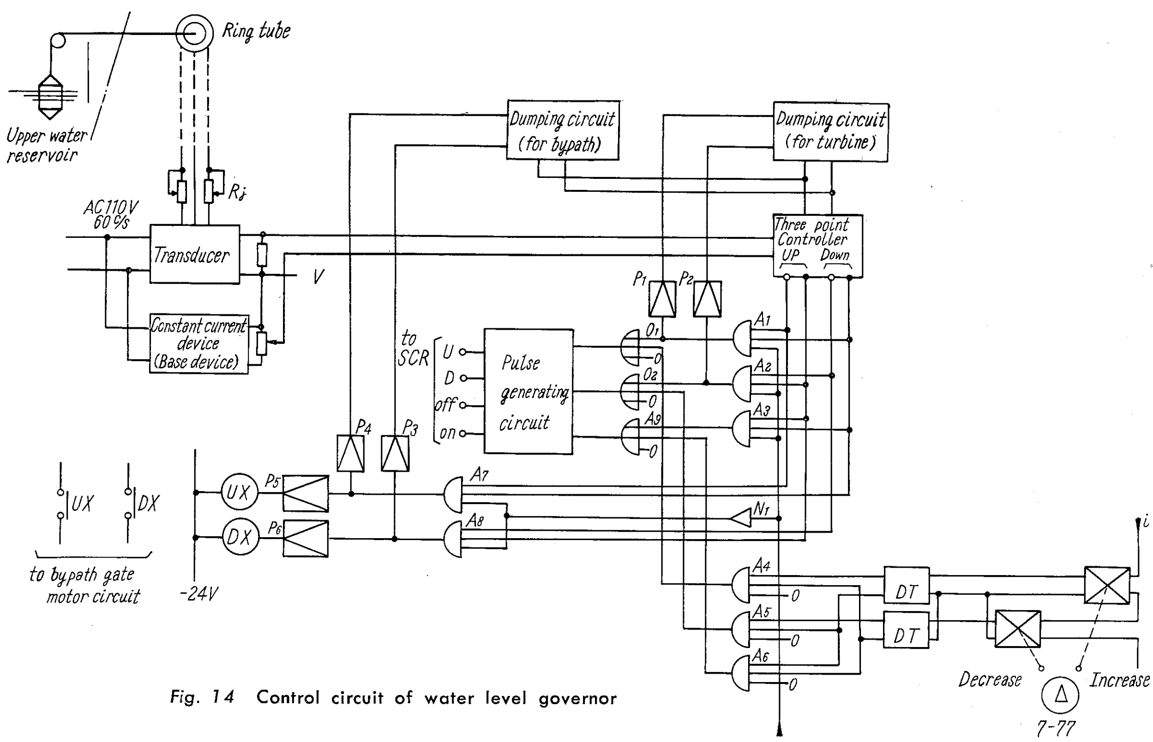


Fig. 14 Control circuit of water level governor

Fig. 14 shows its adjusting circuit. In the logical circuit, the operation of a water governor by the turbine and by bypath operation may be automatically switched by the conditions of AND circuit, and, at the same time, the dumping circuit used for stabilization is automatically switched.

These are some of the advantages derived from making the controllers of the digital system which permits the connection between the circuits to be conducted contactlessly.

Each station has a reservoir at the end of its release waterway from which water is led to the turbine or the bypath through a pressurized water channel. At the entrance to the turbine is a surge tank and when water is governed there is a proper vibration between the upper reservoir and the surge tank, and, when the effect of this influence is felt, it is difficult to obtain stability of the automatic control system.

In other words, the equation of movement of every part in the water channel or water course in *Fig. 15*, for instance, is:

$$\rho,\ L,\ A_p\frac{du_p}{dt}+\sigma u_p^2=A_p(P-P_2) \quad \text{.........(1)}$$

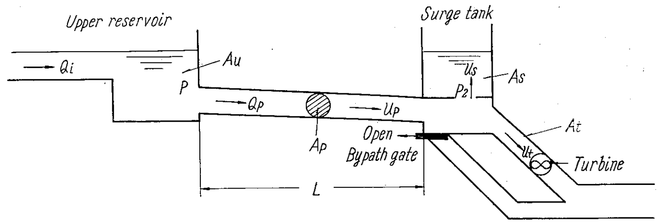
and at the surge tank,

$$\rho,\ A_s,\ u_s=\frac{A_s}{g}\cdot\frac{d(P_2-P)}{dt} \quad \text{..............(2)}$$

And, from the theorem of continuation,

$$\rho,\ A_p,\ u_p=\rho,\ A_s,\ u_s+\rho,\ A_t,\ u_t \quad \text{...........(3)}$$

stands, and, between the guide vane opening and the flow speed of water as it passes the turbine, the following relationship exists:



A_u : Upper reservoir area of equal value (m²)
A_s : Surge tank area of equal value (m²)
A_t : Turbine flow-in area of equal value (m²)
A_p : Tunnel area (m²)
u_p, u_s, u_t : Flow speed of each part (m/s)
P : Pressure at outlet of upper reservoir (kg/cm²)
P_2 : Pressure at entrance of surge tank (kg/cm²)

Fig. 15 Equivalent figure of water course at water level governor operating

$$u_t=K\sqrt{P_2}\cdot G \quad \text{....................(4)}$$

ρ: quantitative volume of water σ: loss factor
g: gravity speed K: constant
G: guide vane opening

The block diagram of the water governing circuit is shown in *Fig. 16*, of which water course conditions Nos. 1 and 2 may be expressed in the following manner from the transfer function as led from formula (1) through (4).

$$\frac{\Delta u_t}{\Delta G}=\frac{2A}{2A+B} \quad \text{....................(5)}$$

$$\frac{\Delta u_p}{\Delta u_t}=\frac{A}{B} \quad \text{......................(6)}$$

Provided,

$$A=\frac{L}{g}\cdot\frac{A_s}{A_p}S^2+\frac{2\sigma,\ u_p,\ A_s}{\rho,\ g,\ A_p^2}S+1$$

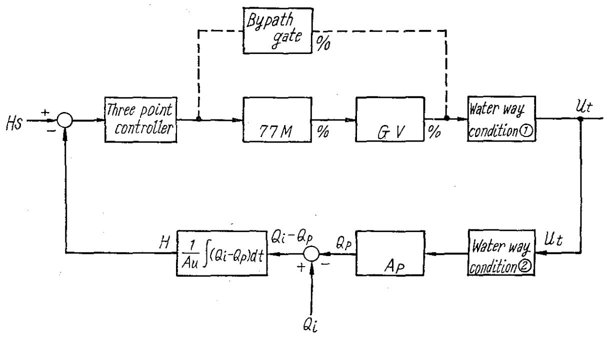


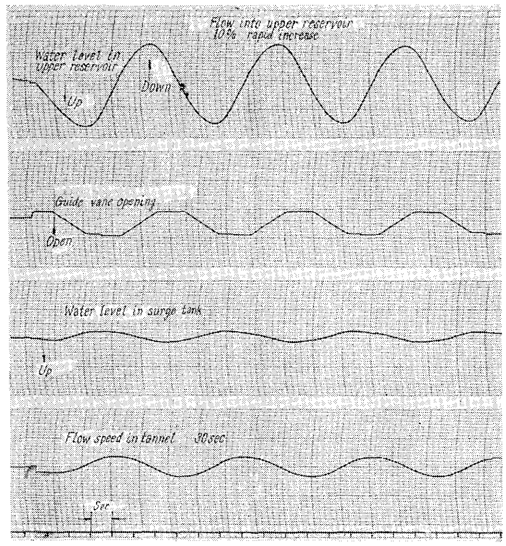
Fig. 16 Block diagram for water level governor

$$B=\frac{\rho,\ L,\ u_t,\ A_t}{P_2A_p}S+\frac{2\sigma,\ u_t,\ u_p,\ A_t}{P_2,\ A_p^2}$$
$$S\equiv d/dt$$

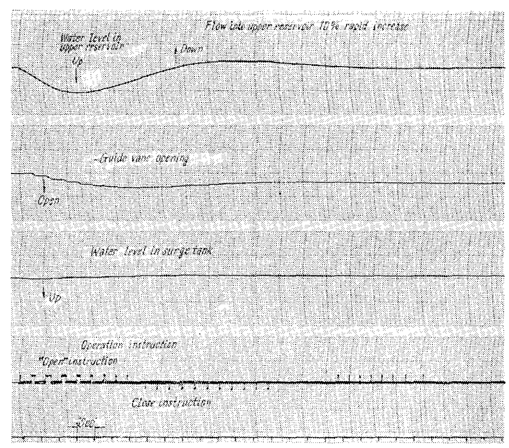
Fig. 17 represents an oscillogram after adjustment of various parts of the controller by an analogue computer and confirmation of a stable domain.

Fig. 18, meanwhile, shows an oscillogram of the water level governor test on the field. *Fig. 17* shows the proof that stabilized operation is possible, while from *Fig. 18* it may be seen that a three-point controller with the addition of a dumping circuit and adjustment of sampling time, the application of integral control of a water level governor in such a complicated water system as this produces an essentially different set of good results in comparison with the contact type controller of the past. Since in this instance *77 M* (load limiting motor) is driven by SCR, the output of the transistor from the three-point controller is directly conveyed to the motor. In this respect also it has a lot to contribute to the stability of a water level governor circuit.

Fig. 19 shows an oscillogram of water level governor tests by a bypath gate valve. Usually in a water system using a tubular turbine a runner vane is activated to compensate for the lowering of efficiency due to head fluctuation for acquisition of high



(a) When unstable



(b) When stable

Fig. 17 Analysis of transient response in water level governor by analogue computer

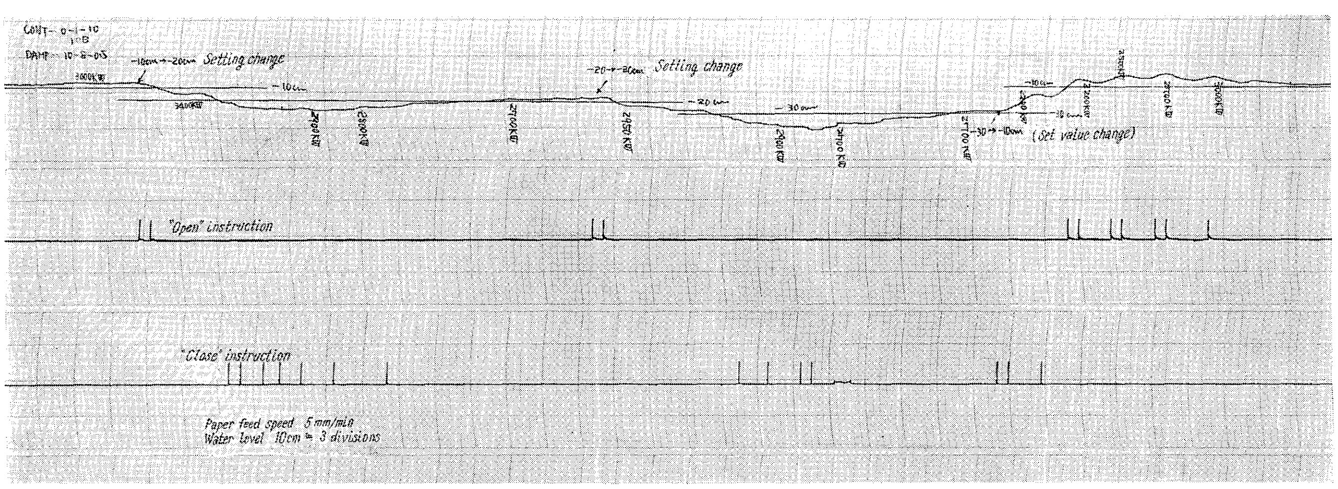


Fig. 18 Oscillogram of water level governor test by water turbine at J2 P.S.

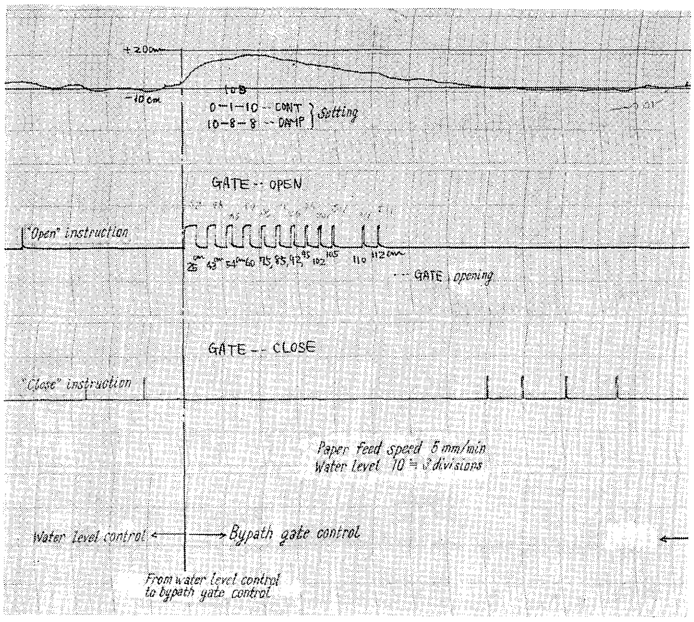


Fig. 19 Oscillogram of water level governor test by bypath gate valve at J2 P.S.

efficiency operation. However, at the present power stations, because the water level is always maintained at a constant point at both the upper and the lower reaches, it is sufficient to fix the relationship between the guide vane and the runner vane at a certain position and it is possible to operate it at a high degree of efficiency without requiring the installation of any extra device for highly efficient operation.

6. Contactless Control Device of Operation Motors

Since voltagewise it is impossible to directly control the speed regulating motor, load limiting motor and voltage adjusting motor with the present transistor following instructions from transistorized and contactless speed automatic matcher, the automatic water level governor and the voltage adjusting device as the control circuit voltage of these operation motors is rated as d-c 110 v, a contactless control system by SCR (silicon controlled rectifier element) has been developed and employed.

Fig. 20 shows the basic circuit of the present control system.

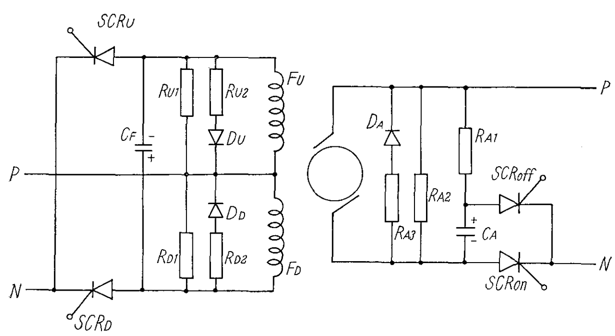


Fig. 20 D-c motor control circuit by SCR

In the diagram, starting and stopping of the motor are accomplished by opening and closing of the armature current for which purpose SCR_{on} and SCR_{off} are provided. On the other hand, in order to control the rotation of the motor in accordance with the operating instructions of "up" and "down" from the adjusting devices, the motor field system is made of an intermediate tap system as in the diagram and up field F_U and down field F_D are provided in the form of field windings and, as a means of selecting and exciting either of them SCR_U and SCR_D are provided respectively.

When, for instance, an up operation is desired, give "on" instructions to the gates of SCR_{on} and SCR_U and energize them, then the up field system F_U is excited and at the same time armature current flows and the motor rotates in the up direction. In this condition, SCR_{off} and SCR_D are in the "off" position so that the commutating condensers C_A and C_F are charged in the polarity as indicated in the diagram.

When the stop is desired, give "on" instructions to the SCR_{off} gate, and SCR_{off} is energized and at the same time the commutating condenser C_A is charged and, by the force of electric potential, SCR_{on} is immediately subjected to negative potential, so that it is arc-quenched and gets in the "off" state. Consequently, the motor stops and C_A is charged in the reverse potential from the start, and at the next starting order, SCR_{off} arc suppressing action takes place by the "on" position of SCR_{on}.

In the case of the "down" operation, likewise give "on" instructions to the gates of SCR_{on} and SCR_D, and as soon as SCR_D goes "on" SCR_U is arc-suppressed by the charging potential of the commutating condenser C_F, and the field system is excited on the down side, and the motor rotates in the down direction. In other words, SCR_U and SCR_D control their respective field exciting directions and at the same time serve mutually as arc-quencher for the other SCR.

Control instructions from the transistor circuit of each adjusting device to SCR need be given in an insulated manner. For this, a pulse transformer for insulation is used which transforms output variation of the transistor of the adjusting device output into pulse and then applies it to the gate of SCR.

In practical application of this circuit, it is required that frequent and yet arbitrary instructions from the adjusting devices be faithfully followed and that the "on" and "off" actions of each SCR be made as required. Therefore, a system is taken in which temporal harmony between the charge time constant and control instructions of each commutating condenser be securely maintained in the transistor instructions control circuit. Ample consideration is also paid for stability against surge or control voltage fluctuation at the power station accompanying operation of various strong electrical equipment installed alongside this device.

The sequence built up of these device comprises all contactless switches, limit switches, adjustors and regulators and they are connected by the logical output of 1, 0, so that from the start of operation until its end input is transmitted without using any electromagnetic switches.

In establishing the sequence,

(1) The circuits are so constructed as to eliminate any faulty operation by means of interlocking a logical element to other related elements if the logical element should go wrong.

(2) When defects should take place, these defects are indicated so that it is possible to repair them and to retrieve the swiftest possible recovery of equipment as a whole to normal operating conditions.

The signals instructing the opening and the closing of electromagnetic solenoids and switches are placed under relatively severe conditions as regards current volume and induction, etc. so that at the present stage signals are relayed by connecting electromagnetic relays to the output amplifier.

V. CONCLUSION

Research has been advanced regarding the protection of power equipment and the static rendition of controls of apparatus. In addition to making all kinds of protective relaying equipment static, it has now become possible to render power station apparatus controls static.

As for the basic elements, it has been confirmed that their performance is superior as applied to protective relaying equipment and that they prossess a number of advantages as transistorized relays. However, on the other hand, there have been a number of problems involved in making static operation controls of power stations which are the central core of electric power apparatus and equipment—problems different from those relating to the protective relaying equipment.

Indeed it is unnecessary at this time to point out the merits that are obtained from making controls of equipment for power stations static.

While it is certainly true that these have already been successfully used in the realm of protective relaying equipment, these are the first transistorized operation control devices to be used for a power station, and we pay great respect to the courage with which Hokuriku Power Electric Co., Inc. and the other sources concerned have decided on its use. Gratitude is also due them for the generous cooperation rendered at the time of installation, adjustment and tests.

Today, the tendency is for more static controls and we have been highly reassured by the success of this first application of static controls and we would like to invite constructive criticisms regarding the use of these controls in the future for which we would be highly grateful.