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SYNCHRONOUS AIR-BLAST CIRCUIT BREAKER FOR ONE CYCLE INTERRUPTION DELIVERED TO HOKURIKU ELECTRIC POWER CO., INC. AND KYUSHU ELECTRIC POWER CO., INC.

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I. INTRODUCTION

Synchronous air-blast circuit breakers for one cycle interruption have been developed by Fuji Electric after many years of research and develoment. These circuit breakers, which feature an interrupting time within a one cycle and an arcing time of 1.5 ms, have attracted much attention from persons concerned both in Japan and overseas. Recently a 300 kv 25,000 Mva synchronous air-blast circuit breaker for one cycle interruption and two similar 120 kv 5000 Mva circuit breakers were supplied respectively to the Shintoyama Substation of Hokuriku Electric Power Co., Inc. and Nagasaki Substation of Kyushu Electric Power Co., Inc. These circuit breakers have already been placed in operation. This report contains an outline description of the synchronous air-blast circuit breakers for one cycle interruption.

II. RATINGS

The ratings for the synchronous air-blast circuit breaker for one cycle interruption, of the type supplied to the Shintoyama Substation, Hokuriku Electric Power Co., and the Nagasaki Substation, Kyushu Electric Power Co. are shown in *Table 1*.

Table 1 **Ratings**

	Shintoyama S.S. Hokuriku Electric Power Co. Inc.	Nagasaki S.S. Kyushu Electric Power Co. Inc.
Model	RF791N/250 /2000DS	RF791G/100 /1200 DS
Rated Voltage (kv)	300	120
Insulation Level (kv)	Ac 460 Imp. 1050	Ac 230 Imp. 550
Rated Current (amp)	2000	1200
Rated Frequency (cps)	60	60
Breaking Capacity (Mva)	25000	5000
Making Current (ka)	131	65.6
Rated Short Time Current 2sec (ka)	48.1	24.0
Total Breaking Time (cps)	1	1
Closing Time (sec)	0.12	0.2
Control Voltage (v)	Ac 200 Dc 100	Ac 200 Dc 100
Operating Pressure (kg/cm^2·g)	15	15
Duty Cycle	O–0.35 sec–CO -1 min–CO	O–1 min–CO -3 min–CO
Rule	JEC-145	

III. STRUCTURE, OPERATION

A detailed description of the construction and operation of synchronous air-blast circuit breakers for one cycle interruption is presented in another part of this Review (*Fuji Electric Review*, Vol. 11, No. 4, 1965). Therefore, only a general outline on the synchronous ABB is presented in this report. With respect to those having rated voltages of 120 kv and 300 kv, basic construction and operating principles are identical, and they differ only in duty cycle. This report describes the 300 kv synchronous ABB used with a high-speed reclosing device.

The basic interrupting operation of this air-blast breaker is shown in *Fig. 1*. *Fig. 2* shows the operating system of the 300 kv synchronous ABB.

The secondary current of the current transformer is supplied to the synchronous pulse generator, and,

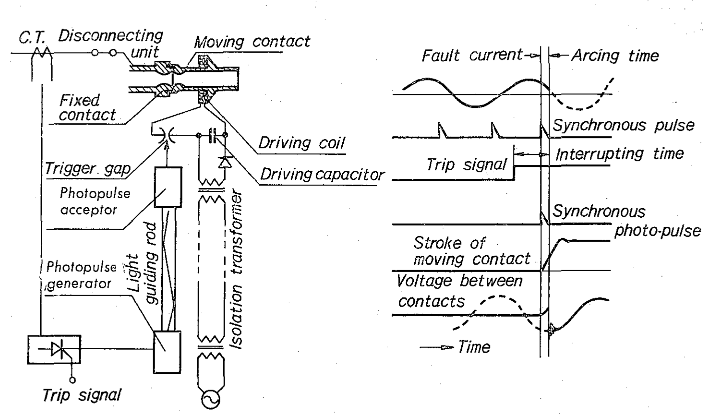

Fig. 1 Schematic connection and process of synchronized interruption

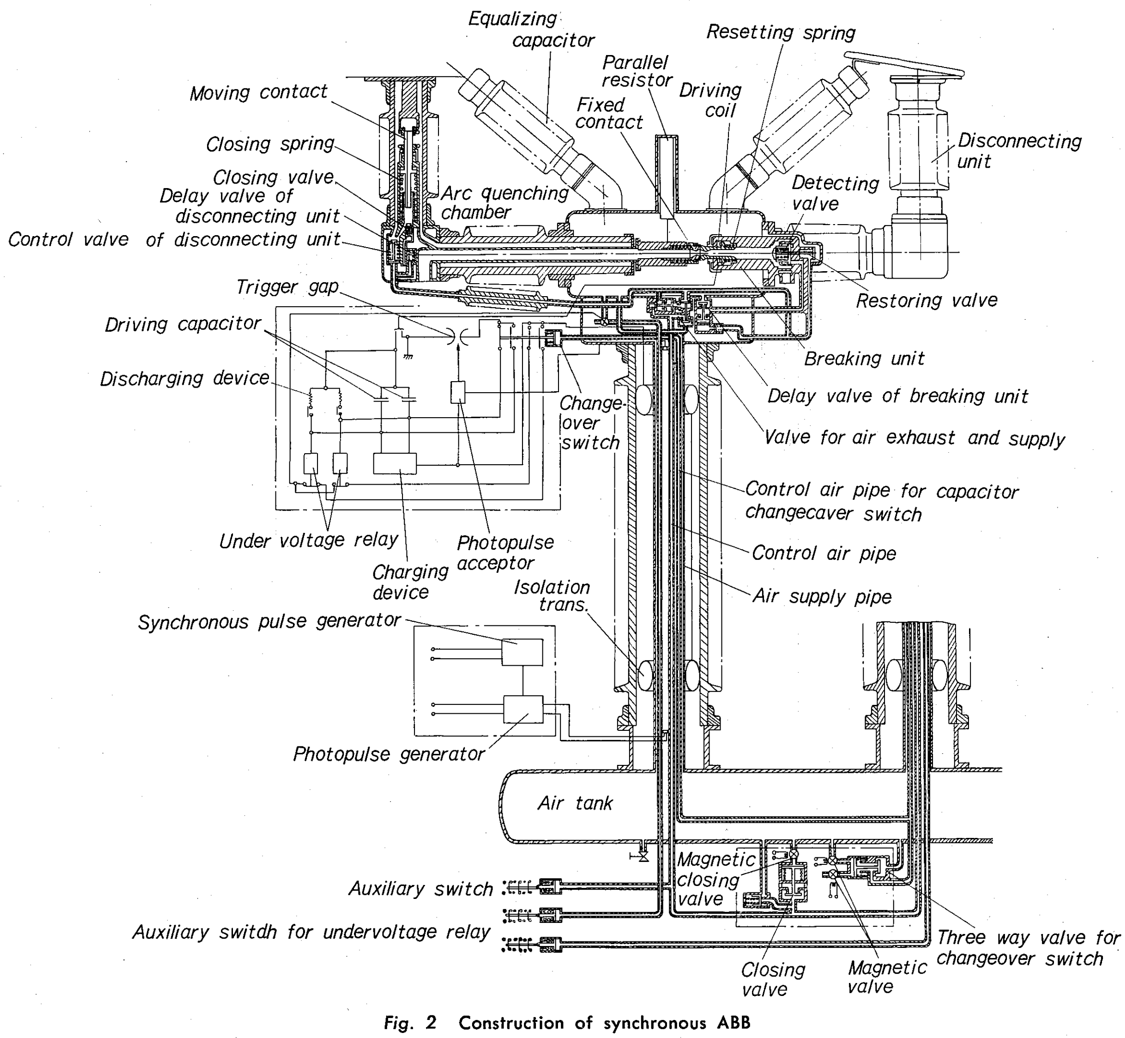

Fig. 2 Construction of synchronous ABB

when a trip signal is given, a synchronous pulse is generated before 1.5 milliseconds to the zero point of the short-circuit current. This synchronous pulse is changed to a photopulse by the photopulse generator, and is then transmitted to the high potential section. In the high potential section the received photopulse is reconverted to an electrical pulse by a photopulse acceptor to ignite the trigger gap. The driving capacitor is constantly charged through an isolation transformer. When the trigger gap is ignited, this energy is applied to operate the moving contact of the breaking unit, and interruption is completed at the next zero current point of the synchronous pulse.

The construction and features of each section of this breaker are as follows:

1) Control section

The control section consists of an airtank and closing and trip control equipment. Closing control equipment contains a closing valve and a 3-way valve for the changeover switch. The trip control equipment has a synchronous pulse generator, photopulse generator, etc. The synchronous pulse generator generates a synchronous pulse at current greater than 1100 amp in the 300 kv synchronous ABB supplied to the Hokuriku Electric Co. and current greater than 500 amp in the 120 kv synchronous ABB supplied to the Kyushu Electric Power Co., depending upon current ratio and maximum shortcircuit current. When the current is smaller than this value the synchronous pulse generator generates an output approximately 7 ms or 22 ms later. However, since line current is small, there is no problem with respect to contact erosion and interruption characteristics although synchronous interruption is not performed.

With an increased shortcircuit current, the secondary current waveform of the detection current transformer may be deformed cousing core saturation. This sometimes adversely affects detecting characteristics of the synchronous pulse generator. Therefore, if interrupting current is very large, adequate consideration must be given to selection of a suitable current transformer that will satisfy these conditions.

Differing from conventional breakers, semiconductors are employed in the trip control equipment and photopulse acceptor. These semiconductors are designed for complete stability and have been adopted only after having successfully undergoing stringent tests. Readers are referred to the detailed description on the composition of these semiconductors presented in another part of this paper.

2) Insulation section

The insulation section consists of a supporting insulator. Isolation transformers for transmitting energy to the high potential section, an air supply pipe for transmitting highly compressed air, control air pipes, and light guiding rods for tra nsmitting photopulses are all contained in the supporting insulator.

The isolation transformer has a shield construction with full consideration given to prevent internal resonance from surge voltages, which might cause layer shorts in the windings, and to eliminate adverse effects on the semiconductors and other components in the control equipment.

3) High potential section

The high potential section, installed on the supporting insulator, consists of a breaking unit, disconnecting unit, operating section, and related systems. The breaking unit is installed in an arc quenching chamber under compressed air with resistors for equalization of potential distribution and suppression of overvoltage which is connected in parallel with the breaking unit. The disconnecting unit is connected in series with the breaking unit.

An electromagnetic drive system is used for the operation of the moving contact of the breaking unit. This drive system is the most significant characteristic of this synchronous ABB. By trip signal, the electric charge from the driving capacitor flows into the driving coil of the breaking unit and repulsive force drives the moving contact which is tightly coupled electromagnetically with the driving coil. When this occurs, the energy of the electric charge of the driving capacitor is changed into the driving energy of the moving contact. In an extremely short time, the moving contact is moved to the opening position for interruption. The moving and fixed contacts of the breaking unit have nozzle construction referred to as double flow.

The operating section is closed by the arc quenching chamber and contains a photopulse acceptor, capacitor charging device, driving capacitor, trigger gap, valve for air exhaust, supply capacitor-changeover switch, and related system components.

The valve for air exhaust and supply acts as a control valve. This valve is used only in the 300 kv synchronous ABB. This valve provides a closing time of 120 ms. This is much shorter than that of the 120 kv synchronous ABB which has a closing time of 200 ms. The rated reclosing time of the 300 kv synchronous ABB is 0.35 sec. However, it has been verified that this time can be shortened to 0.18 sec. This means that the operating characteristics of this synchronous ABB are sufficient to satisfy future requirements for extensive decrease in reclosing time for stability of the power system, etc. Each system component operates in the following sequence.

1. Interruption

When a trip signal is given, a synchronous pulse is generated by the synchronous pulse generator receiving output from the current transformer. This synchronous pulse is then used to generate a photopulse from the xenon flash lamp of a photopulse generator. The photopulse is then transmitted to the high potential section. The high potential section receives the photopulse, which ignites the trigger gap, and opens the moving contact of the breaking unit. The time difference between the arrival of the synchronous pulse and the opening of the moving contact is on the order of 10 μsec and is nearly negligible. Therefore, the contact opens 1.5 ms before the current zero point. With the opening of the moving contact, compressed air is blasted into the nozzle. This air blast extinguishes current at the next zero point.

The compressed air, blasted through the nozzle, assists in the opening position of the moving contact, and, while air-blasting is performed through the moving contact nozzle, the moving contact is held open. The restoring valve is also operated by dynamic pressure of the blast air to release air into the control air pipe. This control air operates the dis-connecting unit and is sent to the ground side through the air pipe and the valve for air exhaust and supply in the operating section. The moving contact of the disconnecting unit also has nozzle construction and air blasting is accomplished during the opening operation to interrupt the current passing the parallel resistors of the breaking unit. Just after the operation of the disconnecting unit, the delay valve of the breaking unit, and then the restoring valve of the breaking unit which operates to cut off air exhaust from the moving contact, are operated. This decreases the force of the blast air, the moving contact is returned to its closing position by the spring, and interrupting motion is completed.

2. Closing

When a closing signal is given, the compressed air supplied to the control air pipe during interruption is exhausted through the closing valve. Then, through the action of the valve for air exhaust and supply control air in the high potential section is exhausted, and the operating valve of the disconnecting unit and delay valve of the breaking unit are operated. The moving contact of the disconnecting unit is closed by spring force under highly compress ed air. The restoring valve returns to a position so that a constant gap is maintained and the air exhaust of synchronous interruption is not affected. This completes the closing operation.

The air-blast circuit breaker has a special air system. During interruption, compressed air is sent from the high potential section to fill the control air pipe and during the closing operation air is exhausted through the ground side. Trip free is also available with ease by merely operating this closing valve.

3. High-Speed Reclosing

The interruption of this air-blast circuit breaker is accomplished by energy stored in the driving capacitor. Therefore, when interruption is accomplished, the subsequent interrupting operation is not performed until the capacitor recharges. Therefore, in high speed reclosing two driving capacitors are used and a driving capacitor is switched through trip signals to rapidly prepare for the next interrupting operation.

This air-blast circuit breaker, unlike existing air-blast circuit breakers, in addition to control air requires an ac power source to provide power for the driving capacitor in the high potential section. However, this ac power source need not be too stable since there are no particular problems when power source current is interrupted for periods of less than 0.2 sec and a continuous power source is not especially required. When the above stated conditions are not satisfied with respect to power source stability an ac power source is required.

The operating power sources for the equipment supplied to the Hokuriku Electric Power Co. and Kyushu Electric Power Co. are described in the following for reference.

Both Hokuriku Electric Power Co. and Kyushu Electric Power Co. used their own power sources installed in their substations.

* 300 kv air-blast circuit breaker supplied to Shin-toyama Substation, Hokuriku Electric Power Co., Inc.
  Normal: 1.2 kva
  Short time (30 seconds): 8 kva

* 120 kv air-blast circuit breaker supplied to Nagasaki Substation, Kyushu Electric Power Co., Inc.
  Normal: 0.4 kva
  Short time (30 seconds): 1.0 kva

IV. TEST RESULTS

Prior to delivery, this equipment is completely tested in accordance with JEC–145. Routine and reference tests are applied. The tests confirmed that optimum performance was obtained from the

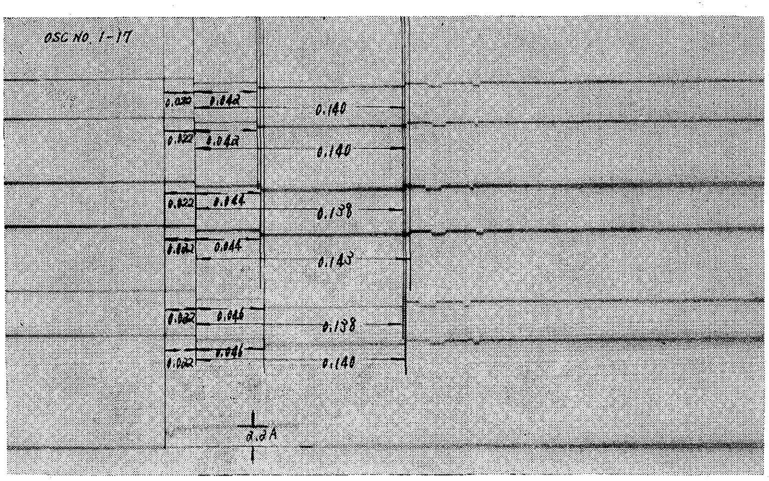

Fig. 3 Oscillogram of operating test (120 kv)

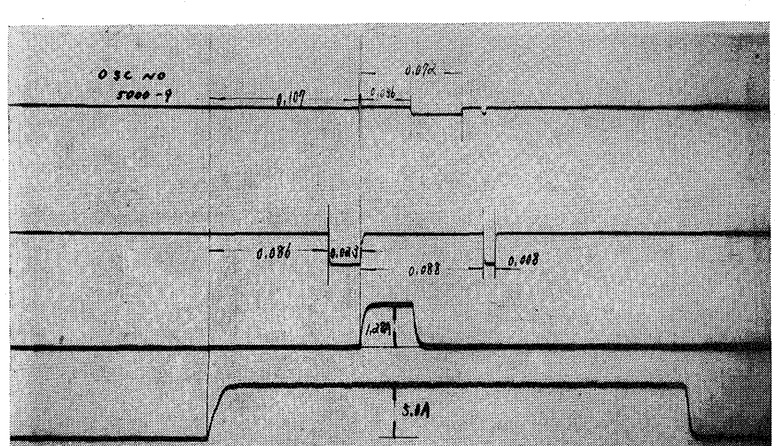

Fig. 4 Oscillogram of operating test (300 kv)

Table 2 **Results of Interrupting Test (120 kv)**

		Supplied Voltage (kv)	Making Current (amp)	Breaking Current (ka)	Arcing Time (ms)	Restriking Volage			Operating Pressure (kg/cm²·g)	No. of Breaking Unit	Test Circuit
						Transient restriking voltage (kv)	Frequency (kc/s)	r·r·r·v (kv/μs)			
Breaking of Short Current	O	10.0	—	10.0	1.6~2.0	96.5	5.15	0.99	12.7	1	Fuji equivalent test
	O	10.0	—	19.0	1.9~2.0	120	3.6	0.87	12.7	1	〃
	O	10.0	—	27.2	1.8~1.9	111	2.25	0.5	12.7	1	〃
Phase Opposite	O	10.0	—	17.6	1.7~2.0	152	2.0	0.61	15.0	1	〃
Short Line Fault	O	10.0	—	18.4	2.0	16.7	43.5	1.45	15.0	1	〃
Non-Synchronous Interruption	O	10.0	—	21.0	6.5~7.2	116	2.56	0.6	15.0	1	〃
Close	CO	—	85	—	—	—	—	—	—	2	Direct test

Table 3 **Results of Interrupting Test (300 kv)**

		Supplied Voltage (kv)	Making Current (ka)	Breaking Current (ka)	Arcing Time (ms)	Restriking Voltage			Operating Pressure (kg/cm²·g)	No. of Breaking Unit	Test Circuit
						Transient recovery voltage (kv)	Frequency (kc/s)	r·r·r·v (kv/μs)			
Breaking of Short-current	O	63	—	5.56	1.36	100	3.65	0.73	12.7	1	Direct test
	O	11.0	—	15.75	1.3~1.4	94.5	9.7	1.83	12.7	1	Fuji equivalent test
	O	11.0	—	26.6	1.1~1.2	88.7	5.35	0.947	12.7	1	〃
	O	10.8	—	53.0	1.1~1.3	78.0	1.7	0.265	12.7	1	〃
Phase Opposite	O	10.8	—	24.6	1.3~1.5	160	1.61	0.515	15.0	1	〃
Short Line Fault (6.6 km)	O	10.8	—	37.2	1.0~1.2	53.5	13.5	1.45	15.0	1	〃
Short Line Fault (3.3 km)	O	10.8	—	40.0	1.0~1.1	28.0	17.8	1.0	15.0	1	〃
Non-Synchronous Interruption	O	19.8	—	29.8	7.9~8.4	87.0	1.56	0.272	15.0	1	〃
Close	O—0.25 s—CO—1 m—CO	10.8	130	47.0	1.0~1.4	20.6	6.5	0.268	15.0	1	Direct test

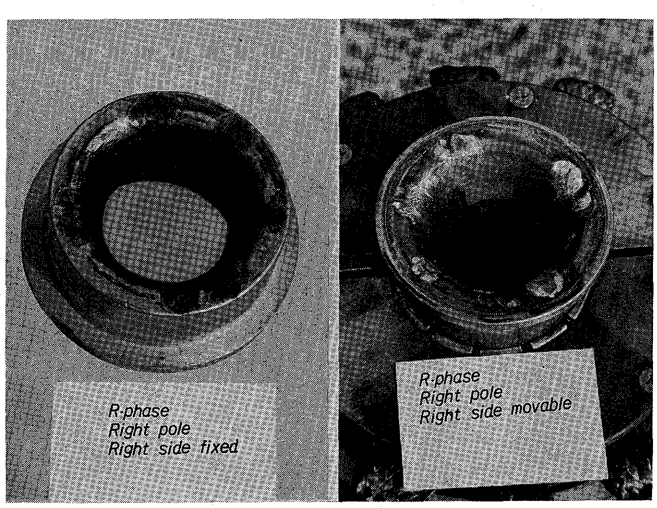

Fig. 5 Moving contact after interrupting test

120 kv and 300 kv circuit breakers. The following details are furnished with respect to test results.

1. Switching Test

There were no noticeable defects in mechanical components, such as packing and springs, or electrical components, such as semiconductors, after switching 10,000 times. The oscillograms in *Figs. 3* and *4* show test results. The opening time with no load supplied from the current transformer has been set at 22 ms for the 120 kv circuit breaker, and 7 ms for the 300 kv circuit breaker.

2. Temperature Rise Test

Measurements are made before and after the interrupting tests with respect to the contact of the breaking and disconnecting unit. Temperature rise exhibited no difference. This is clear evidence of the outstanding performance of the synchronous interruption. Temperature rise for individual contacts was far below the rated value.

3. Short Circuit Test

Short circuit interrupting tests were conducted using a Weil equivalent circuit. Results are shown in *Tables 2* and *3*. Contact damage was negligible although the same contacts were used throughout the tests without exchange. There was, as described above, no appreciable temperature rise in comparison to the temperature rise before interruption. The contacts subjected to this test are shown in *Fig. 5*. The slight damage seen on the butt of the contact is characteristic of synchronous breakers.

4. Small Current Interrupting Test

Interrupting performance was optimum. No overvoltage was produced and there was no restrike in the interruption of capacitive current. Overvoltage was suppressed to less than 2.0 with respect to inductive current. Test results are as shown in *Tables 4* and *5*.

5. Test for Double Line-to-Ground Fault and Out-Of-Phase Interruption

Neither the 120 kv nor 300 kv breakers showed any defects as a result of the double line-to-ground fault or out-of-phase interruption tests.

6. Short Line Fault Interrupting Test

The π–type artifical line of 1 km was used for the 120 kv breaker with 6.6 km and 3.3 km applied to the 300 kv circuit breaker. The test was conducted using a Weil equivalent circuit. Optimum results were obtained with outstanding characteristic of r.r.r.v.

7. Contamination Test

The contamination tests were performed under single phase arrangements. Their contamination withstanding results were on the order of 0.03 mg/sq cm.

8. Others

Under the dielectric strength test, the 120 kv circuit breaker was tested with 230 kv ac and 550 kv impulse voltage and the 300 kv with 460 kv ac and 1050 kv inpulse voltage with no defects. Nor did they show any defects under pressure test, flash-over, and wet tests. The short-time current test was applied under maximum interrupting currents of the 120 kv and 300 kv circuit breakers. No defects were seen in switching performance after the short-time current test. Oil-insulated transformers are employed in the supporting section, single-stage for the 120 kv and two-stage for the 300 kv. These transformers were tested separately from the related sections with respect to various dielectric strength tests. The single-stage transformer was tested with 230 kv ac and 525 kv impulse voltage and the single-stage transformer of the 300 kv circuit breaker was tested with 250 kv ac and 605 kv impulse voltage, in consideration of voltage distribution to the individual stages.

An analyzing test and a 695 kv chopped-wave test were also conducted to determine whether the circuit breakers would withstand a still impulsive voltage during switching. After these tests, a further test was made to verify that no internal corona occurred with respect to single line-to-ground fault.

The 300 kv circuit breaker is delivered together with the current transformer. A synchronous interrupting test was applied to the combination current transformer and breaker. The synchronous interrupting test was optimum.

Other tests were also conductcd with respect to influence on semiconductor devices, caused by overvoltages which could be supplied through the line. Results are given in detail in a separate paper.

V. CONCLUSION

The foregoing description applies to the synchro-air-blast circuit breakers for one cycle interruption supplied to the Shintoyama Substation of the Hokuriku Power Company, and the Nagasaki Substation of the Kyushu Electric Power Company.

As can be seen from this description, the circuit breakers have many outstanding features, far excelling those found in conventional circuit breakers.

We are confident that they will contribute toward increased reliability, safety and economy in power systems, when used with still higher speed relay equipment for system protection which may be developed in the future.