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MINIMUM SIZE DC HIGH SPEED AIR CIRCUIT BREAKERS

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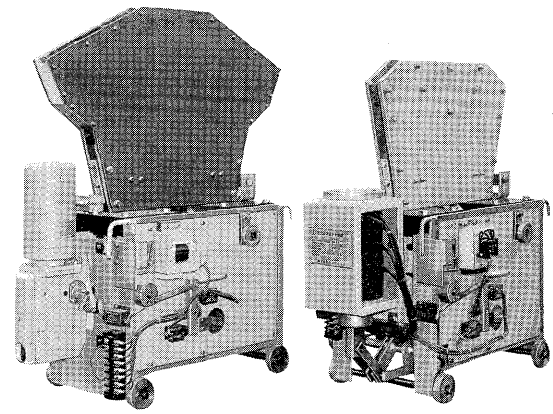
I. INTRODUCTION

In the remarkable progress made in semiconductor rectifiers, considerable emphasis has been placed on the role of DC high speed air circuit breakers which serve as protectors for the rectifiers. There has also arisen recently the need to make substations more rational and much more compact because of the high price of land. This means that it has also become necessary to make the DC high speed breakers much more compact since they are one of the principal components of substations.

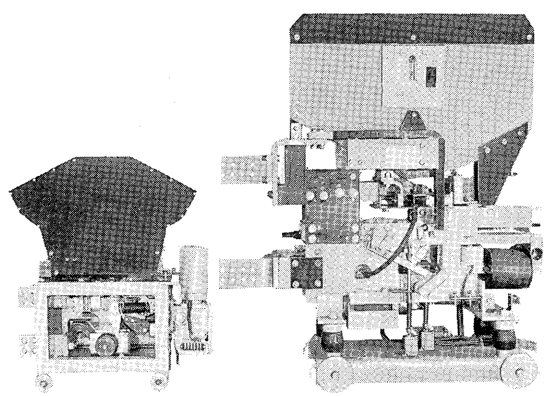
Fuji Electric has recently developed a minimum size high speed circuit breaker with non-polarity characteristics for 750 V or 1,500 V based on the techniques of the Siemens Co. Since a specially developed arc extinguishing method and an ingenious operating mechanism are used, this breaker has the same capabilities of the standard type although its volume is 25% and weight 20% of the standard type. This new breaker meets the requirements of modern substations.

This breaker was developed on the basis of new ideas. A tripping mechanism which is operated by a signal from the exterior and a mechanical maintaining mechanism are used and the breaker also has all the capabilities of an air circuit breaker so that it can be employed in a wider range of applications than usual. This article gives an outline of this breaker.



BWV 152 (Motor operated) BWV 82 (Solenoid operated)

Fig. 1 Minimum-size DC high speed air circuit breaker



BWV 152 RPa 252

Fig. 2 Comparison of BWV 152 and RPa 253

II. FEATURES

1) Compact and light weight

The weight and volume are only 20% and 25% respectively of those of the Fuji Electric standard breakers. Refer to *Fig. 2* for a size comparison.

2) Stable circuit breaking capability because of unique arc quenching method

The arc is controlled by a U-shaped arc horn in the 750 V arc quenching chamber and a rationally arranged grid in the 1,500 V arc quenching chamber. In this way, a stable circuit breaking capacity is achieved, the arc quenching chamber is more compact and the arc space is minimized.

3) Ingenious operating mechanism and minimum number of " live " parts

Heat generation is limited since the circuit through which the current passes is very short. Chattering during closing has been eliminated by attaching a weight to the moving contact, and the arcing contact and main contact form a single unit. The links in the operating mechanism have been simplified by making a long hole in the hinge of the moving contact arm. Opposing springs perform three actions : closing, contacting and breaking.

4) Mechanical holding system

Since a mechanical holding system in employed, there is no need for a holding power supply. Variations in operating current are small because tripping detection is not related to changes in the operating voltage.

5) Non-directional current breaking possible

Since tripping is performed by the force of a magnet located in the circuit throught which the current passes, exactly the same breaking operation is performed for currents in either the positive or negative directions.

6) Various types of trippling such as overcurrent tripping possible

Automatic tripping of overcurrents is provided by the magnet force. Breaking is carried out by operation of the tripping mechanism when a signal comes from the exterior. Therefore, various types of tripping such as voltage, no-voltage and time-overcurrent tripping are all possible.

7) Easy maintenance and inspection

As the above features indicate, construction is of the simple unit type so that there are few inspection points and it is possible to replace the arc quenching chamber and contacts in about 5 minutes.

III. RATINGS AND SPECIFICATIONS

The ratings and specifications of this breaker are listed in *Table 1.*

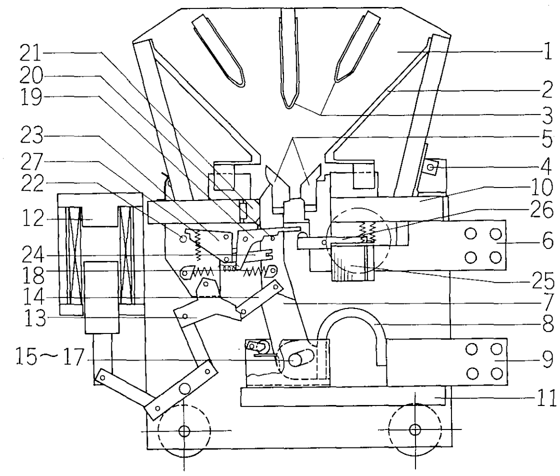
IV. CONSTRUCTION AND OPERATION

This breaker is a DC high speed circuit breaker in which opening and closing are performed by a spring which is compressed by a mechanical hold system. Operation is by means of a solenoid or a motor. The two type : BWV82 (750 V) and BWV152 (1,500 V) can be converted simply by replacing the arc quenching chamber.

Fig. 1 shows outer views of the BWV82 (solenoid operation) and BWV152 (motor operation) types and

***Table 1* List of ratings and specifications**

Type	BWV 82	BWV 152
Rated voltage (V)	DC 750	DC 1,500
Rated current (A)	2,000	
Breaking capacity (Short circuit current) (kA)	50 (at di/dt=3×10^6 A/s)	
Short circuit trip direction	Non-polarity	
Short circuit trip range (kA)	2~4, 3~6	
Operating control voltage (V)	DC 100/110	
Closing time (s)	0.5	
Dimensions (width×depth×height)	366×784×770	366×784×895
Weight (kg)	90	100



① Arc quenching chamber
② Arc horn
③ U-shaped arc horn
④ Hinge
⑤ Contact
⑥ Upper conductor
⑦ Moving contact arm
⑧ Flexible lead
⑨ Lower conductor
⑩ Insulating base
⑪ Insulating base
⑫ Operating device
⑬ Joint lever
⑭ Joint lever
⑮ Hinge bolt
⑯ Long hole
⑰ Long hole
⑱ Spring
⑲ Latch lever
⑳ Latch roller
㉑ Stopper
㉒ Semicircle pin
㉓ Trip lever
㉔ Span lever
㉕ Yoke
㉖ Anchor
㉗ Spring

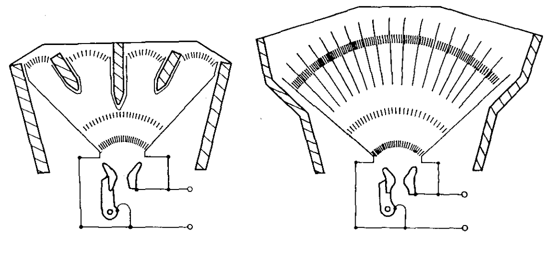
Fig. 3 Construction of BWV 82

Fig. 3 is a construction diagram of the BWV82 type. The breaker is made up of an arc quenching chamber, current carrying part, switching operation mechanism, operating device and accessories. The current carrying part and switching operation mechanism are contained in a frame made of grounded metal and side plates. A wheel is attached to the frame and it is possible to convert between draw-out type and a fixed type by attaching or removing the draw-out device and main circuit disconnecting switch. The arc quenching chamber is attached so that rotation is possible by means of a hinge. Thus the contacts can be inspected simply by lifting up the arc quenching chamber.

The current carrying part consists of upper and lower conductors, and a flexible lead. Heat generation is limited because the current path is as short as possible. The moving contact arm is made of a Cu–Cr alloy which has high tensile strength and current conductivity but is very light weight. Chattering during closing has been eliminated by attaching a weight of a suitable size to the arm. With this construction, it has been possible to make the arcing contact and the main contact in a single unit (patent application number 1970–23058)

The switching operation mechanism contains a moving contact with a long-hole hinge, a jointed link mechanism which transfers the operating pressure, a lock lever, a tripping mechanism and opposing pull-type springs. All of these are rationally arranged. The springs are extended by operation of the moving contacts. They provide pressure for closing and contacting, and during breaking, they operate as breaking springs. Overcurrent tripping is performed by the attraction of a clapper type magnet located in the current path. Since the operation is the same for currents in both the positive and negative directions, a non-directional operating current can be set by means of the rotary dial type calibrated setter.

The operating device is located on the front surface of the breaker and the two are connected by means of the switch mechanism and the lever. It is therefore simple to convert between solenoid and motor operation. On the sides of the breaker are arranged such accessories as various types of tripping devices for manual tripping, an auxiliary switch, a frequency counter, a switching indicator and a limit switch. These devices are used to control the various switching operations.



(a) 750 V (b) 1,500 V

Fig. 4 Arc extinguishing principle

1. Arc extinguishing method

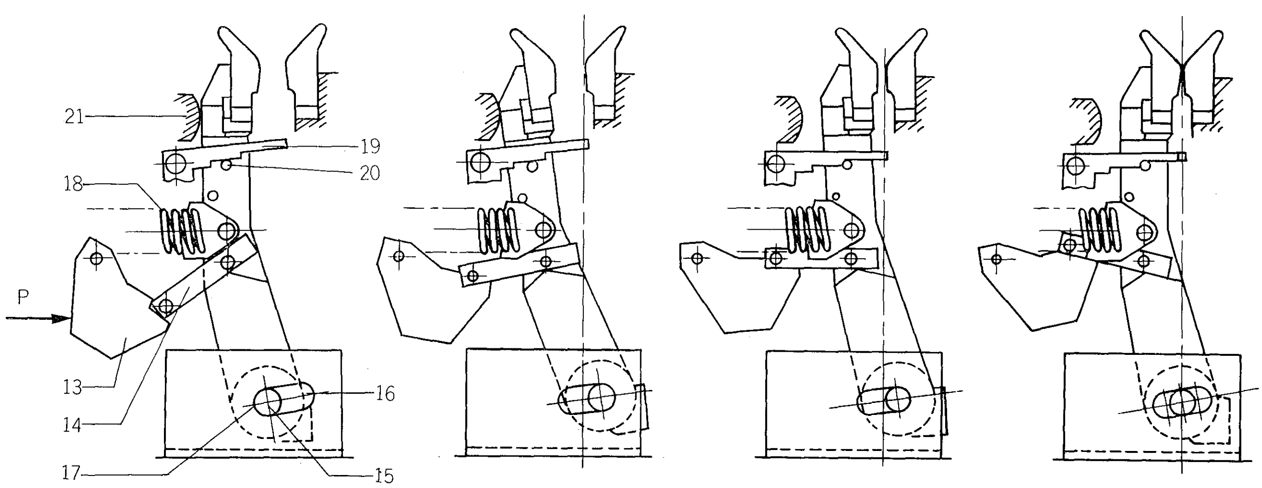
The arc quenching chamber consists of arc extinguishing walls which are resistant to the high arc temperatures, an arc horn to lead the arc into the arc quenching chamber and a U-shaped arc horn (for 750 V) or a metal plate grid (for 1,500 V). All of these components are arranged compactly.

When the contacts are open, the arc is extended into a loop shape by the electromotive force of the arc itself as well as the arc horn located in the arc contact. With this arrangement, the arc is blown instantaneously into the arc quenching chamber. This arc is then divided into several loops by the U-shaped arc horm as shown in *Fig. 4* (a) for the 750 V arc quenching chamber. In this way, arcs of sufficient length are obtained and they are extinguished by pressure. As is shown in *Fig. 4* (b), the 1,500 V arc quenching chamber contains a grid of about 70 plates in which a series of small gap arcs are formed. These arcs are extinguished by utilizing recovery of the insulation yield strength near the electrodes after the current has passed through. By dividing the arc in this way, the arc is expanded uniformly and the arc voltage can be controlled. It is therefore possible to achieve stable breaking characteristics and reduce the size of the arc quenching chamber.

2. Closing operation

Joint lever ⑬ is rotated at the center of its support point by closing pressure P from the operating mechanism. The moving contact is pushed by joint lever ⑭. At that time, hinge bolt ⑮ is pushed from its position in *Fig. 5* (a) to the end of long hole ⑯. When it reaches the position in *Fig. 5* (b), stopper ㉑ moves as the support point (center of rotation) and then the end point ⑯ is used as support point. When condition (c) is achieved, spring ⑱ is extended by movemement of the moving contact arm.

When the opposite joint levers ⑬ and ⑭ form a straight line, latch lever ⑲ locks with latch roller ⑳. When these joint levers move past the dead point, latch lever ⑭ moves up and away from lever ⑬ as is shown in *Fig. 5* (d). At the same, the moving contact arm is rotated by the extended spring at a high speed around the rotational point formed



(a) Open circuit (b) Pull spring (c) Locking condition (d) Closed circuit

Fig. 5 Operating mechanism

by the latch lever and latch roller. Closing is then complete (spring closing system).

In this condition, contact pressure is applied by spring ⑱. When the contact is new, hinge bolt ⑮ is in the center of long hole ⑯—⑰ in the closed position. When the contact is worn, it will shift toward the ⑰ end and should be replaced.

3. Automatic breaking by overcurrent tripping equipment

When the current reaches the value set on the rotary dial type scale, latch lever ⑲ locked by roller ⑳ to anchor ㉖ extended by yoke ㉕ is released. Then spring ⑱ rapidly pulls the moving contact arm toward the breaking position and the breaker is open.

4. Breaking by various tripping devices

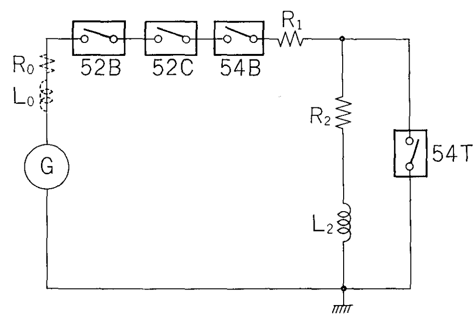
This device can be mechanically tripped by a manual button or voltage, insufficient voltage and time limit tripping devices which are operated by signals from the exterior. When these tripping devices operate or the manual button is pushed, semicircular pin ㉒ is rotated and trip lever ㉓ is released. This trip lever is then rotated counterclockwise by the tension of spring ㉗ and latch lever ⑲ is released from its lock position with roller ⑳. Breaking then occurs in the same way as mentioned previously. Spring ㉗ is extended again by span lever ㉔ when breaking operation of the moving contact arm is completed. The semicircular pin and the trip lever are then locked and the breaker is ready for closing.

V. TESTS

1. Short circuit breaking tests

In this high speed breaker, high speed current limit breaking to minimize damage due to short circuit faults and also reciprocal limiting of the arc voltage in keeping with the insulation of the circuit devices are required.

In order to check if these requirements are met, Fuji Electric performed the AC equivalent breaking test as per JEC-152 (1961) using a 1,500 MVA short circuit testing device. The test conditions were sustained short circuit current $I_m=50$ kA and surge factor $di/dt=3\times10^6$ A/s. Since the specified di/dt could not be obtained in the standard circuit for the 750 V test, a reactor with the same inductance value as the generator was connected in parallel with the breaker as shown in *Fig. 6*. The test was performed in a special circuit to which a circuit voltage of 750 V was applied with the generator voltage at



G: 1,500 MVA short circuit generator
52B: Protective breaker for AC
52C: Closing switch
54B: Protecitve breaker (HSACB)
54T: Test breaker
R_0: Internal resistance of generator
L_0: Internal inductance of generator
R_1: Series resistance
R_2: Parallel resistance
L_2: Parallel inductance ($\fallingdotseq L_0$)

Fig 6 Circuit of 750 V AC equivalent breaking test

Table 2 **Results of AC equivalent breaking test**

Short circuit current 50,000 A $di/dt=3\times10^6$ A/s Setting current 6,000 A

Type	OSC No. QTE-	Test frequency (Hz)	Generator voltage peak value (V)	Working voltage (V)	Recovery voltage (V)	Breaking current (A)	Opening time (ms)	Breaking time (ms)	Arc voltage (V)	Duty cycle
BWV 152	7398-1	5.8	1,800	1,800	1,550	24,500	6.5	35	2,200	0
	7398-2	5.8	1,800	1,800	1,630	24,300	7.0	32	2,500	0
BWV 82	7398-5	5.8	1,800	1,800	985	24,300	6.0	20	1,810	0
	7398-6	5.8	1,800	1,800	985	24,300	6.5	20.5	1,820	0

Table 3 **Results of $di/dt=(7\sim10)\times10^6$ A/s DC breaking test**

Setting current 6,000 A

Type	OSC No. QTE-	Working voltage (V)	Short circuit current (A)	Breaking current (A)	Opening time (ms)	Breaking time (ms)	Arc voltage (V)	di/dt (A/s)	Duty cycle
BWV 152	7410-1	1,580	43,000	35,200	4.0	12.4	2,820	10×10^6	O
	7410-2	1,580	43,000	35,200	4.0	13.0	2,540	10×10^6	CO
BWV 82	7410-7	780	37,000	24,400	4.4	13.2	1,410	7×10^6	O
	7410-8	780	37,000	24,000	4.0	13.0	1,550	7×10^6	CO

Table 4 **Results of *L* circuit breaking test**

Type	OSC No. QTE-	Working voltage (V)	Breaking current (A)	Circuit inductance (mH)	Arc time (ms)	Arc voltage (V)
BWV 152	7411-1	1,600	4,350	16	81	2,560
	7411-3	1,600	7,850	8	79	2,370
BWV 82	7411-5	800	3,900	16	79	1,760
	7411-7	800	6,900	8	61	1,440

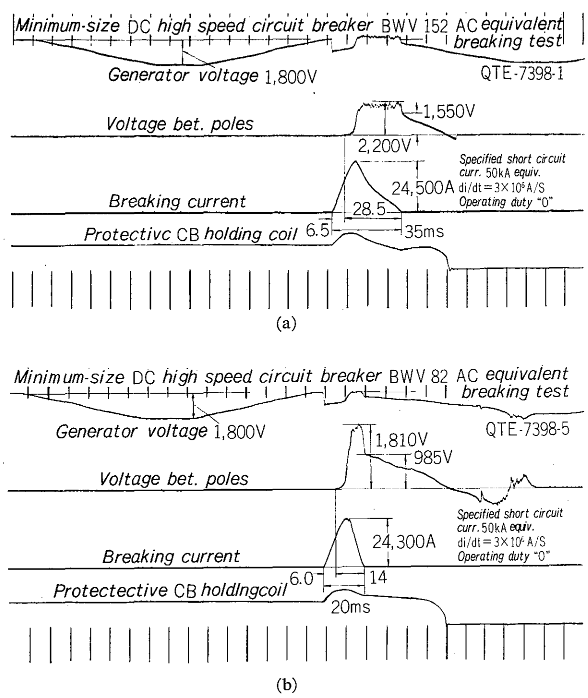


Fig. 7 **Oscillograms of AC equivalent breaking test**

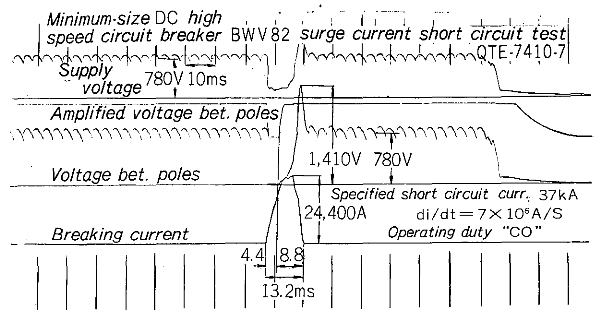


Fig. 8 Oscillogram of di/dt=7×10⁶ A/s breaking test

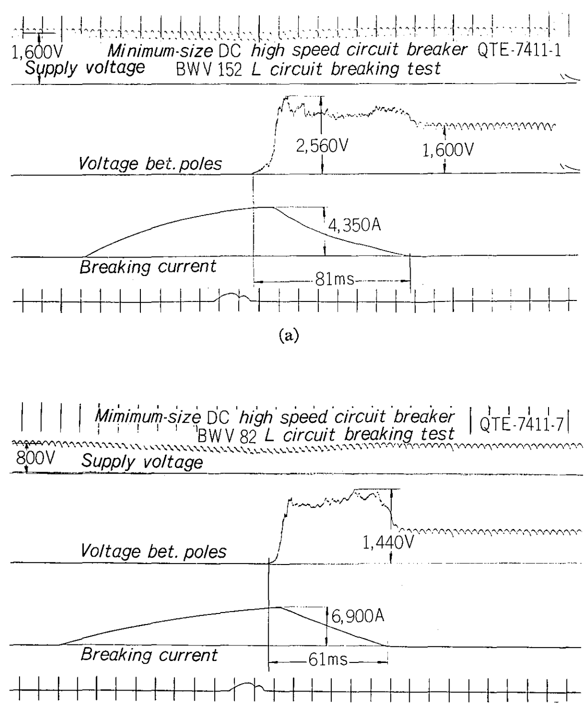


Fig. 9 **Oscillograms of L circuit breaking test**

1,500 V. The results are listed in *Table 2* and a typical oscillogram is in *Fig. 7*. The current limit value was kept low to insure a short opening time and rapid start of current limiting. After current limiting, the arc voltage was suppressed with an arcing time a little longer than that of the Fuji standard type. A high surge current breaking test with $di/dt = 7$ to 10×10^6 A/s was performed using DC short circuit test equipment by assuming that a fault occurred near the substation at a point where the current rise factor is high. The results of this test are given in *Table 3* and a typical oscillogram is shown in *Fig. 8*.

2. L circuit breaking test

Sometimes there is breaking of large inductive currents which are not tripped by overload or faults but by operating conditions or manually. In such cases, complete breaking is also possible. *Table 4* shows the results of this test and *Fig. 9* gives typical oscillograms.

3. Small current breaking test

In breaker where arcs are extinguished by their won force, it is usually difficult to interrupt small currents with a small electromagnetic extinguishing power. For such cases, a device with an air blower is generally included as an accessory. In this breaker, however, the arc is extended effectively by means of the arc horn attached to the contact, and it is possible to interrupt small currents without any accessories for cooling by the arc quenching wall. The results of this test are shown in *Table 5* and a typical oscillogram is given in *Fig. 10*.

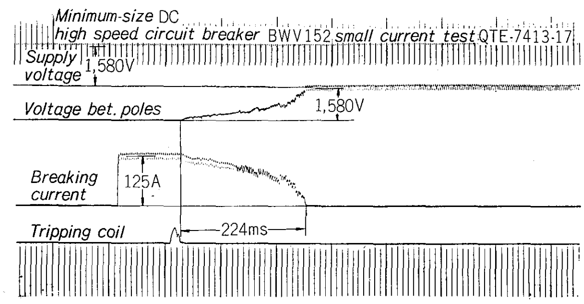


Fig. 10 Oscillogram of small current breaking test

***Table 5* Results of small current breaking test**

Type	Working voltage (V)	Breaking current (A)	Circuit inductance (mH)	Arc time (ms)
BWV 152	1,580	9.5	0	308～354
	1,580	26.5	0	390～478
	1,580	50.0	50	375～470
	1,580	125.0	50	224～327
BWV 82	780	9.0	0	195～230
	780	33.5	0	243～270
	780	60.0	50	235～270
	780	125.0	50	164～200

4. Temperature rise tests

The results of the temperature rise tests are shown in *Table 6*. These tests were carried out to confirm that the breaker could continuously withstand the rated current.

***Table 6* Results of heatrun test**

Through current 2,000 A, Through time 6 h

Measuring point	Temperature rise value (℃)	Standard value (℃)
Upper terminal	36	40
Contact	64	75
Flexible lead	41	60
Lower terminal	34	40

5. Continuous switching tests

No-load continuous switching tests were conducted 20,000 times at the rated operating voltage. No abnormalities arose in any part of the breaker and there were no changes in switching characteristics after the tests. Therefore, these breakers can be used continuously.

VI. CONCLUSION

The DC high speed circuit breakers BWV82 and 152 described here were developed on the basis of new ideas and should contribute to the compactness and economy of substations since they are of minimum size, excellent in terms of actual performance and also easy to maintain. They should also be applied over a wider range than usual since protective coordination is possible by means of various types of tripping devices.