The Air-Blast Circuit Breaker

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The air-blast circuit breaker

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The current design trends for today's high voltage air-blast circuit breakers are described. The special advantages of using air as a switching medium are related to the requirements of the present and future needs of e.h.v. and u.h.v. supply networks.

Some research currently being carried out throughout the world with relevance to gas-blast interrupters is mentioned.

1. Introduction

The air-blast interrupter breaks load and short-circuit currents by means of a rapid flow of air across the arc which is drawn when the contacts are separated. At the supply current zero, rapid de-ionization takes place and the residual arc path is replaced by compressed air of high dielectric strength – present designs use air at up to 7 MPa (70 atm) pressure.

The air-blast circuit breaker in Britain arose from work by the U.K. Electrical Research Association on oil breakers. It was found that it was the hydrogen released from the oil by the arc and not the oil itself that did most of the work and a gas blast device was then proposed and tested.

The patent was taken out in 1927, but due to the unchallenged supremacy of oil breakers it was not until the late 1940s that air blast was used commercially as a circuit-breaking medium in Britain following its use in Germany and Switzerland.

Table 1. Typical voltage and short circuit ratings of air-blast breakers

system voltage / kV	66	110–132	220	275	330	400	500	735
s.c. rating / MVA	2500 to 5000	3500 to 10000	5000 to 20000	10000 to 20000	10000 to 20000	25000 to 35000	30000 to 40000	35000 to 60000
no. of breaks per phase	2	2 to 4	2 to 6	4 to 8	4 to 8	4 to 12	6 to 12	8 to 12

It was quickly realized that the performance could be raised by the use of higher pressures and by connecting interrupters in series. Thus 66, 132 and 275 kV designs were produced with a sequential isolator and in 1964 three U.K. designs were produced operating at pressures of 2.5 MPa (25 atm) and with up to 12 breaks per phase to give a rating of 35000 MVA for the 400 kV system voltage.

World ratings have increased generally as shown in table 1 and the first 1100/1300 kV u.h.v. ratings are expected by the 1990s. This short report reviews some aspects of current and future air-blast circuit-breaker designs.

2. Basic constructions

(*a*) *Interrupter types*

All air-blast circuit breakers follow the principle of separating their contacts in a flow of air established by the opening of a blast valve. The arc which is drawn is usually rapidly positioned centrally through a nozzle where it is kept to a fixed length and is subject to maximum scavenging by the air flow. Arrangements vary but can be grouped into three types as shown in figure 1: (*a*) axial flow with axially moving contact (as in the original E.R.A. patent); (*b*) axial flow with sideways-moving contact; (*c*) radial flow with axially moving contact.

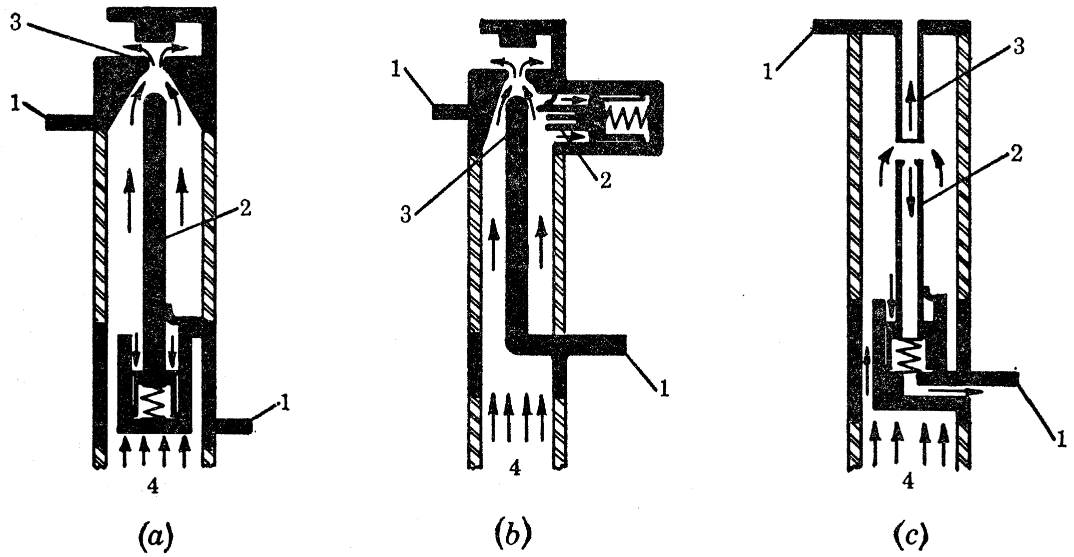

Figure 1. Basic constructions of gas-blast interrupter. (*a*) Axial flow with axial moving contact; (*b*) axial flow with side moving contact; (*c*) radial flow with axial moving contact. 1, terminal; 2, moving contact; 3, fixed contact; 4, blast pipe.

(*b*) *Position of air receiver and blast valve*

The local air storage may be at earth potential and air supplied to the interrupters through insulating pipes or it may be mounted at the level of the interrupters at line potential and the air fed through insulating pipes. The blast valve may also be in one of many positions and examples are given below:

(i) Receiver on the ground and blast valve at low level. Here the blast pipe must be filled before the interrupters are supplied with air.

(ii) Receiver on the ground and blast valve at high level. This reduces the amount of air wasted but requires an insulated drive to the blast valve.

(iii) Live receiver and blast valve. Shorter opening times are possible as the air is stored near the interrupter units.

Pressurized-head breakers such as the Reyrolle design of circuit breaker shown in schematic form in figure 2 do not need a sequential isolating switch as insulation across the open contacts can be maintained by the high dielectric strength of static compressed air. This system is now used for almost all e.h.v. and u.h.v. designs. However, it is the practice of most system operators to open an adjacent isolator when pressurized circuit breakers are standing open for long periods.

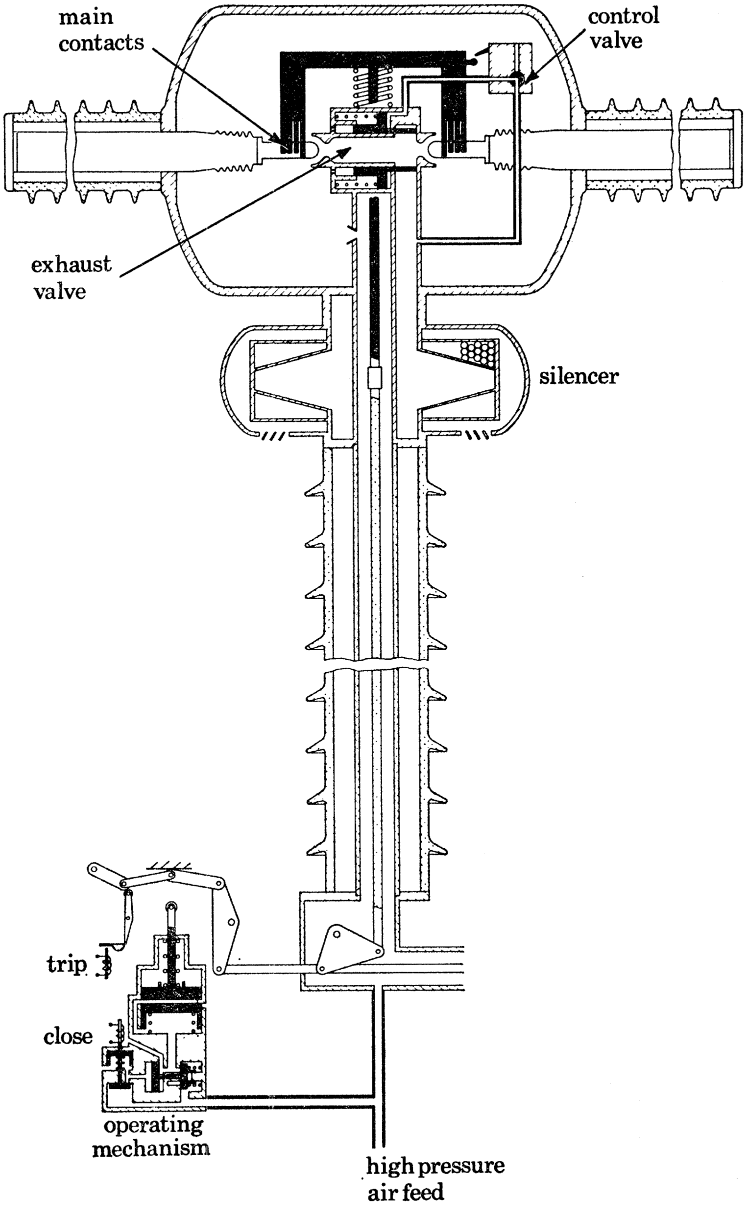

Figure 2. Schematic diagram of pressurized-head circuit breaker.

3. The use of air as a switching medium

Air has been the most convenient switching fluid for many years due to its ready availability and low cost. The increasing use of SF_6, especially for metalclad designs, has prompted further examination of the merits of the two gases for different situations. For the u.h.v. designs both gases can overcome the technological problems – it is the final costing that will determine the correct circuit breaker for a given situation. (The high-voltage minimum-oil-volume breaker has not yet been developed to cater for fault current above 50 kA.)

Air (one can usually substitute nitrogen) is readily compressible and the dielectric and switching capabilities have been shown to increase up to at least 15 MPa (150 atm). The use of high-pressure gas permits high mechanism speeds and fast arc scavenging. The arcing products exhausting to atmosphere via a silencing arrangement do not contaminate the switching chamber. For continuous currents greater than 3000 A, the open-type breaker can be more suitable than the metalclad design and, with no gas recirculating plant or gas heating requirements (SF_6 liquefies at 0 °C, 12 atm pressure), the air-blast solution may be the most attractive at u.h.v. levels.

Concerning compressed air systems, the consumption of air used for an opening operation is generally about 15 to 30 m^3 of free air for a 3-phase breaker. It is usual for the local air receiver capacity to be sufficient for two make–break operations to be performed before the air pressure drops below the minimum working pressure. In many designs air is circulated at low pressure to prevent moisture condensation on insulating surfaces – typically 0.5 m^3 of free air per hour may be employed.

The compressed gas is generated either at the circuit breaker or at a central point with a ring-main distribution system. The air is initially compressed at between two and three times the circuit breaker working pressure and dried by expansion and chemical dryers to a dew point of less than -40 °C, with a low particulate contamination level.

4. THE USE OF INTERRUPTERS IN SERIES

The breaking capacity of circuit breakers required to match MVA available from power systems has usually been greater than that available at short-circuit testing stations. This has led to the design of multi-break circuit breakers so that a single interrupter could be tested at full current and the correct unit fraction of recovery voltage. In practice this has been found to be satisfactory though further work to determine accurately the correlation between single and multiple break performance under different stress conditions is still being pursued.

Two ways exist of ensuring that the voltage across the breaker is evenly shared by the series breaks. First capacitance, say 500 pf per break, can be added. Alternatively, a resistor–divider arrangement using perhaps 10000 Ω across each break produces good grading, although a series isolating switch in compressed or free air is required to break the small resistor current following clearance of the main circuit.

When switching a fault on a short transmission line, a high-frequency transient voltage (up to 50 kHz, rising at up to 10000 V/μs) appears at the breaker terminals. Under this stress, at the limit of the circuit-breaker performance, post zero conductivity can be present following arc extinction, and it is the conductivity of the individual residual arc columns which determines the voltage grading across each break. The short line fault severity is not expected to increase at u.h.v. levels.

5. VARIETY OF CONSTRUCTIONS AND CIRCUIT-BREAKER DESIGNS

Most manufacturers have adopted a particular design of interrupter unit and used this as a basis for a range of circuit breakers by varying the number of breaks in series and the insulation to earth. Electrically in parallel with each main break is generally added capacitance and/or resistance for voltage division purposes together with low-value resistors (say 200 to 400 Ω per complete breaker) for the damping of short-line fault transient voltages upon opening, and the reduction of line-closing voltage transients.

The A.E.G. (Germany) 'free-jet' design uses a moving upstream contact which establishes an arc partly in free air and partly through an insulated nozzle, where it is subjected to the air-blast. After clearance, the air gaps provide the main insulation across the circuit breaker. These interrupters are used up to 420 kV.

English Electric–G.E.C., Delle–Alsthom (France) and Brown Boveri (Switzerland) use the duo-blast type nozzle arrangement (see figure 1*c*) which has excellent arc scavenging properties. The latter two designs have been used at 735 kV in Canada on the Manicouagan to Montreal line.

In contrast to the above high-voltage designs it is worth while pointing out that air-blast units are used at all voltages down to distribution levels for heavy duty applications. A special example of this is the generator circuit breaker for load and fault switching at power stations. These devices have to break over 100 kA at 20 kV and have a continuous current rating of up to 36 kA (water cooled) or 12 kA (air cooled).

6. Requirements for u.h.v. circuit breakers

The specific requirements demanded of a u.h.v. circuit breaker by system and operator considerations are at present considered to be the following:

(*a*) *Speed of operation*

First of all the breaker must operate with speed. For u.h.v. systems controlling as they do many subnetworks, a loss of stability would be most serious and everything possible must be done to reduce short-circuit detection and circuit breaker operating times. The total interrupting time consists of a time for relay and mechanism operation plus the time waiting for a current zero for interruption. This latter is 10 ms for symmetrical faults but will be longer for asymmetrical or ungrounded 3-phase faults. A total interrupting time, however, of two cycles or 40 ms is possible. As far as the air-blast breaker is concerned, its main contribution is the high operating pressure available for fast mechanism operation and guaranteed arc extinction in one half cycle of arcing.

(*b*) *Limitation of switching surges*

Insulation is not only a major item of circuit breaker cost but also determines the cost of transmission lines, insulator strings and eventually wayleaves and land charges. U.h.v. systems are not troubled so much by lightning surges as by internally produced voltage surges. It appears that closing onto de-energized lines is the greatest problem at present and is of more importance than the case of opening lightly loaded long transmission lines. There are three common solutions or combination of solutions to limit the production of switching overvoltages.

(i) *Synchronization*

In this case a circuit breaker is closed only when, for an unenergized line, the source voltage is zero, or for an energized line, the voltage across the breaker equals zero. The latter zero, however, can be difficult to predict if shunt reactors are on the line. A closing accuracy of 1 ms is needed and so the physical problems are onerous.

(ii) *Closing with resistor insertion*

Closing with a series resistor 7 to 8 ms before the main contacts reduces the surge phenomena both on resistor insertion and subsequent shorting. This insertion time has to allow the last reflected surge to return to the breaker, thus equalling the scatter between poles plus twice the transit time to the end of the line. The optimum resistance value is approximately equal to the surge impedance of the line, i.e. 300 to 400 Ω. If the value chosen is too high, then the major overvoltage occurs on shorting the resistor and if, too low, then the overvoltage occurs on resistor insertion. Figure 3 shows likely overvoltages predicted from a typical transient network analyser study. Obviously the correct choice of supply and line parameters is important for accurate forecasting.

(iii) *Closing with two or more resistors*

An extension of the idea above which further limits the overvoltage by the sequential switching of higher then lower resistance values prior to the closure of the main contacts.

A combination of (i) and (ii) can reduce overvoltages to less than 1.8 p.u. (1.8 times peak system voltage) but a full analytical study is needed for each system contemplated. It must be borne in mind that surges up to 1.5 p.u. can be obtained from straightforward 3-phase switching transients.

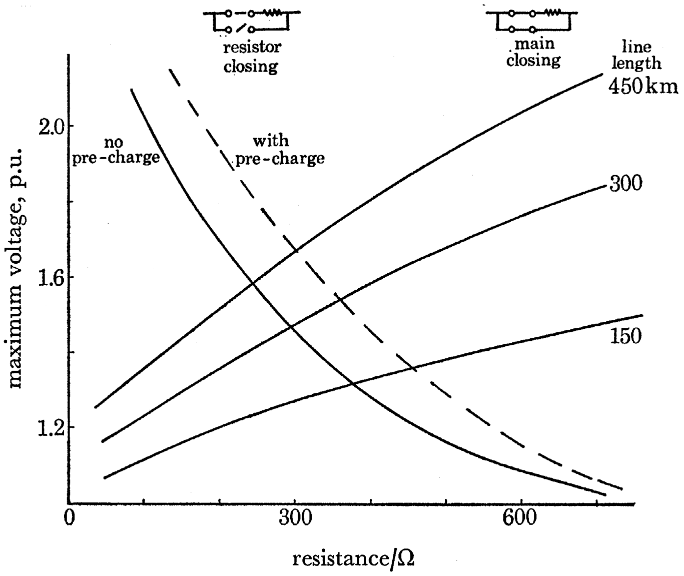

FIGURE 3. Typical overvoltage with resistor insertion.

(c) *Insulation coordination*

Insulation coordination concerns the use of adequate dimensions for the various components of a transmission system such that any overvoltages occurring should be kept within specified limits and if flashover were to occur it would cause limited damage. In circuit breakers there are two main flashover paths: first, to earth via external and internal surfaces and secondly, across the contacts. For the latter, a uniform voltage distribution is desirable and the inter-contact flashover path is made the stronger of the two by 15 % or so. Surge arresters will be used for u.h.v. systems since it is becoming increasingly difficult to coordinate solid and gaseous insulation for different geometries and waveshapes at the highest voltages to ensure that flashover occurs where it will do least damage.

(*d*) *Further aspects*

Two further points could be mentioned in connexion with u.h.v. systems, both connected with the nuisance caused by circuit breakers. First, silencers are fitted to most designs of air-blast breaker and typically consist of expansion and diffusion chambers. The present British maximum for the allowable impulsive noise is approximately 95 dB(A) at 25 m distance and the noise frequency spectrum is generally examined. U.h.v. system components are sited away from centres of population, but operator health is a serious consideration. Secondly, audible corona noise which also produces radio and t.v. interference must be reduced to an acceptable level especially in wet weather by suitable electrostatic stress relief of components.

(*e*) *Probable objectives for u.h.v. designers*

Naturally u.h.v. systems will develop piecemeal in different countries and not all system requirements will be the same, but the specification outlined in table 2 covers the main points likely to be requested for a 1300 kV design.

TABLE 2. POSSIBLE SPECIFICATION FOR 1300 kV CIRCUIT BREAKER

interruption requirements	
normal current	4000 A
breaking current (symmetrical)	50 kA, 100 kA
40 ms total break time	—
two resistor closing stages	—
overvoltage factor	1.5–1.7 times peak system voltage
voltage withstand requirements	
power frequency (1 min)	1650 kV r.m.s. to earth 1900 kV r.m.s. between phases
power frequency wet (30 s)	1500 kV
1/50 μs lighting impulse	3400 kV to earth 3800 kV between phases
200/2000 μs switching impulse	2000 kV to earth 2100 kV between poles

7. RESEARCH INTO CIRCUIT-BREAKER BEHAVIOUR

Short-term development work, as with all products, is directed towards improving existing designs. Longer-term research endeavours to obtain a better understanding of the circuit interruption and dielectric processes and, hopefully, will allow predictions to be made as to the change of performance when changing circuit or breaker parameters. Different problems throughout the world are being examined at this moment, but some common areas retain the attention of many engineers and scientists.

The first is the measurement of arc properties. The arc is useful in all high-power circuit-breaker designs since it is a flexible (both physical and electrical) means of transmitting power until a current zero. Arc theories try to predict the behaviour of an arc in a given circuit under certain energy loss conditions. In addition to obtaining information concerning the physics of arc columns and their dynamic energy balance behaviour, simplified circuit breaker models have been derived in the form of a single nonlinear differential equation in terms of arc conductance, voltage, current and time. One can then determine for a given circuit condition whether the circuit breaker will 'clear' at a current zero or not, though it must be remembered that arcs behave in a statistical fashion with a standard deviation associated with a mean performance level. Theoretical work can also look at the stability of arcs since they can exhibit unstable behaviour which can lead to premature arc extinction, especially in inductive circuits, and subsequent harmful voltage surges.

A knowledge of the air flow characteristics is important to circuit-breaker design since the removal of hot plasma and particulate matter determines both the interrupting ability and also the dielectric strength. Optical methods are generally used to examine the effects of contact and nozzle shapes on turbulence or transient vortex production. Schlieren, interferometric and holographic techniques have all been used to look at air flow with and without the arc present.

Finally, one of the objectives most crucial to the economics of producing multi-unit circuit breakers is the raising of the possible voltage per break both under static and flowing gas conditions. Electrode surface effects, at fields above 10 MV/m and pressures above a few atmospheres, can prove troublesome and irrespective of final 'conditioned' breakdown level only the lowest breakdown voltage can be used as a basis for design calculations. Research, often collaborative, in industry, university and electricity undertakings is seeking answers to the problems posed by electrode surfaces and stray particulate contamination in high electric fields.

8. CONCLUSIONS

The air-blast breaker has proved versatile for every system voltage up to 750 kV. Its future depends on continuing technical progress ensuring its position as an economic item in the supply networks of the world.

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