Paper

Development of Single Break 420 kV GCB

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420 kV-63 kA single break gas circuit breaker (GCB) has been developed [1]. The authors show the steps to develop new interrupting chamber and circuit breaker by using various techniques. At first two interrupting chamber models are considered and investigated conducting electric field calculation and pressure measurement at the top of fixed arc contact, and capacitive current switching test is conducted especially with short arcing times. According to the test results, basic dimensions of interrupting chamber for development is determined. Pre-series CBs are manufactured, then it is confirmed that the breaker can produce the pressure rise in puffer cylinder (ΔP) as the predicted value by calculation and can interrupt short line fault (SLF) current. The driving energy is confirmed to be sufficient by conducting asymmetrical 100% breaker terminal fault (T100a) current interruption tests. All the type tests according to IEC are successfully conducted at the international neutral test station for the breakers for commercial use reflected the above results. The GIS layout with the above mentioned single break GCB can reduce the installation area in half comparing the case with the existing two break GCB.

Keywords: 420 kV-63 kA 1-break CB, capacitive current switching, pressure rise measurement, SLF interruption

1. Introduction

Power demand in densely populated area tends to increase recently one hand and restriction on the number of substations to be constructed increases for the difficulty on obtaining lands or spaces in building or underground on the other hand, which results in high demand for the substations who have high voltage and large power but small installation area. Compact and large capacity GIS is suitable for such substations. GCB, who is the most important component of such GIS, has to be compact. The authors develop 420 kV-63 kA single break GCB for that purpose.

Minimizing of driving energy is concentrated for economical point of view. Achieving capacitive current switching capability with minimum opening velocity is the key for success. The shape and dimensions on interrupting chamber part including puffer cylinder are determined by repeating computer simulation so that reduction on the electric field strength at the top part of the fixed arc contact and preventing the pressure at that part from reducing during opening. Furthermore sufficient ΔP should be obtained for SLF interruption. The driving mechanism is decided to use existing hydraulic driving unit for 300 kV GCB [2] with long and good experience from the view point of reliability, only extending its stroke by 20%.

The circuit breaker with the selected interrupting chamber and driving mechanism is manufactured and tested for T100a on which condition ΔP becomes highest. It is found it has enough driving energy, and is proved to have sufficient capability for the rest of the interrupting duties. Also dielectric, temperature rise, mechanical endurance, and other necessary tests are conducted successfully according to IEC standard.

The driving energy is reduced to 55% compared with existing CB for the same ratings. This breaker also gives an impact to the GIS layout for its installation area to 46% in comparison with the GIS with existing two break GCB.

2. Small Capacitive Current Switching Capability

On small capacitive current switching, dielectric capability between the contacts of CB does not decrease so much caused by residual hot gas by arc after current interruption, because of small current value. It is known that the main factor to give a large influence to dielectric performance and to determine success or failure for interruption is the electric field strength at the top of arc contact and the pressure around it [3][4].

Two interrupting chamber models (Fig. 1(a) model A, (b) model B), who have almost the same principal parts like puffer cylinder but different nozzle parts are investigated. The principal difference of the two is that model A has no insulating cover on the moving arc contact (inner nozzle) and model B has it.

Electric field strength calculation around the arc contacts on each position of travel for opening is conducted

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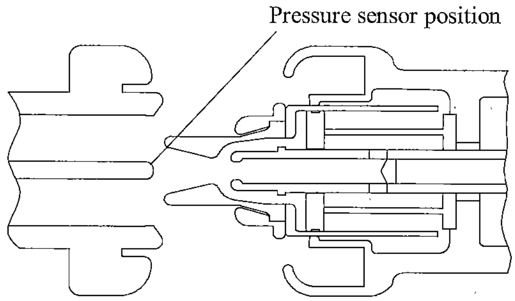
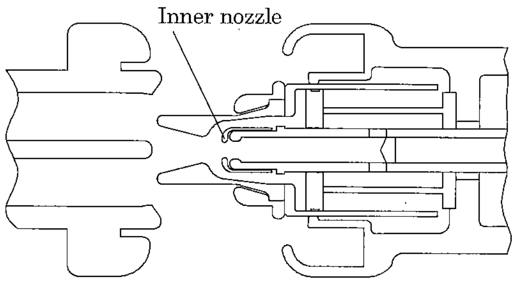


(a) Model A



(b) Model B

Fig. 1. Interrupting Chamber models

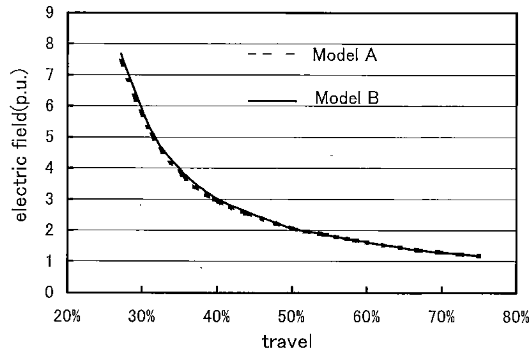
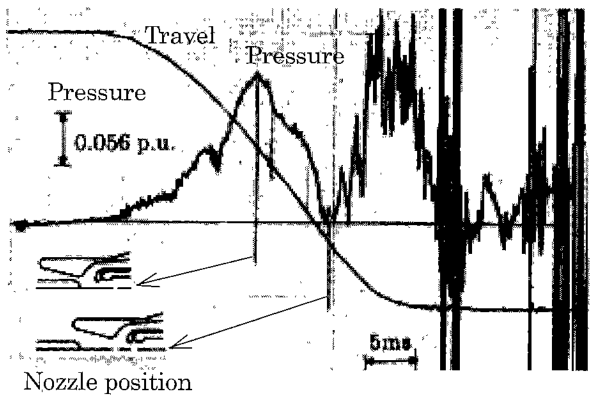
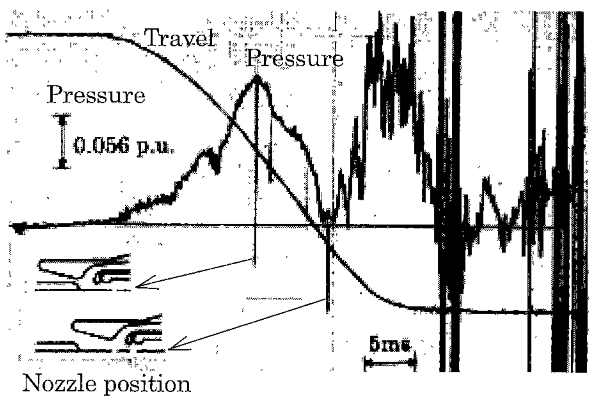


Fig. 2. Electric field strength calculation on arc contact



(a) Model A



(b) Model B

Fig. 3. Pressure measurement at the top of fixed arcing contact

for two models. The results are shown in Fig. 2. The electric field strength is expressed in p.u. based on the value in full open position. The difference of electric field strength between the two models is found very small.

Pressure at the top of fixed arc contact which has highest electric field strength (about 45 degree from the top) is measured by pressure sensor for two models during opening operation. Examples are shown in Fig. 3(a)(b) for model A and for model B. The pressure is expressed in p.u. based on the peak value of ΔP on no-load opening. The pressure sensor locates in the upper stream of nozzle where the gas flow does not begin during the first period of opening. The pressure increases together with that in the puffer cylinder. The sensor part comes to near the nozzle throat where gas flows, the pressure suddenly begins to decrease. Then the pressure becomes lower than that of the nozzle throat, when the pressure in puffer cylinder increases so that the gas flow at the nozzle throat reaches to sound velocity, besides that the sensor part comes to the downstream to the throat and that the sectional area around the sensor part is larger than that of nozzle throat, then the gas flow velocity becomes supersonic. The pressure can be even lower than the filled pressure. After the sensor part reaches to the position with sufficiently large sectional area or out of nozzle, supersonic condition ceases and the pressure at the sensor part begins to increase. Fig. 3(a) and Fig. 3(b) well explain the process mentioned above.

The pressure in Fig. 3(a) for model A decreases down to the filled pressure, but not the case in Fig. 3(b) for model B. The instant of decreasing the pressure in Fig. 3(b) comes later than that in Fig. 3(a). This delay can be the influence of inner nozzle. This is explained as follows. The instant when the sensor part reaches to the position at which gas starts to flow in model B comes later than the case in model A. And the pressure at the nozzle throat, which is located up stream of the sensor part, when the pressure at the sensor part becomes minimum, is higher in model B than in model A.

Capacitive current interruption capability is studied. Dielectric recovery characteristics between the arc contacts, by considering some scattering of flashover voltage after opening, and by calculating electric field strength taking the effect of measured pressure at the top part of fixed arc contact into account, are compared with the applied voltage between the contacts on the most severe condition that the current zero comes just at the moment that the contacts open and current is interrupted.

The results are shown in Fig. 4. It is found that the dielectric recovery curve in model A goes very closely

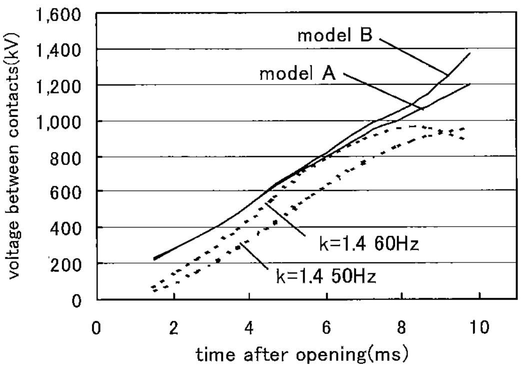


Fig. 4. Dielectric recovery between contacts

Table 1. Results of capacitive current switching test

Polarity*	+				−				Total	Test Condition
Arcing time(ms)	0~2	2~4	4~	Sum	0~2	2~4	4~	Sum		
Model A	20	8	0	28	16	12	2	30	58	k=1.4
	0	0	0	0	0	0	0	0	0	50Hz
Model B	10	17	12	39	8	19	9	36	75	I=400A
	0	0	0	0	0	0	0	0	0	
Model A	5	12	0	17	8	11	0	19	36	k=1.4
	2	0	0	2	0	1	0	1	3	60Hz
Model B	14	5	7	26	12	7	7	26	57	I=400A
	0	0	0	0	0	0	0	0	0	

Upper : Number of shots *Note : Polarity indicates on fixed contact side
Below : Number of re -strikes

crosses to the recovery voltage of k=1.4 60 Hz, which results in some possibility of re-strike for 60 Hz case, but the curve for model B goes rather apart from the recovery voltage of 60 Hz, and model B can be expected to have good interrupting capability even for voltage factor k=1.4 at 60 Hz .

Small capacitive current switching tests are carried out for the two models. The test condition is 420 kV-400 A, k=1.4. For the purpose of research many shots of short arcing times are conducted to find the limit by synthetic test. For 50 Hz condition, both models have quite good results. For 60 Hz condition, model A have some re-strikes, but model B does not have any. The results are shown in Table 1. This is considered to be the cause of higher and later decay of pressure at the top of fixed arc contact part in model B. Then we decide to choose model B as a candidate for the interrupting chamber for development.

3. SLF Interruption Capability

Pre-series GCB which uses the same design as actual production of enclosure, driving mechanism, insulating materials and so on is manufactured using model B, which has a good capability in capacitive current switching tests. SLF test performance is investigated for the pre-series CB.

SLF interruption capability is strongly influenced by the blown pressure to the arc at current zero. Calculations [5] of the pressure rise in puffer cylinder on model B with some slight adjustment of sectional area of the cylinder are carried out for the condition of 63 kA-50 Hz 90% SLF with lockout condition for both SF_6 gas and

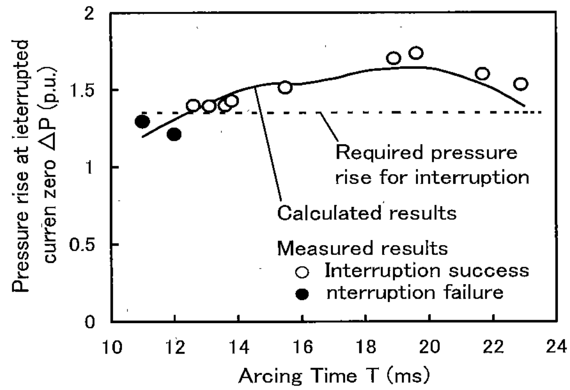


Fig. 5. Pressure rise at current zero on 63 kA-90%SLF interruption

hydraulic pressure of driving mechanism. The pressure rise values at current zero obtained from significant number of calculations are shown in Fig. 5. Pressure is expressed in p.u. based on maximum no load pressure rise on the same condition as above. Necessary pressure rise is also indicated in Fig. 5, which is obtained considering the study results for SLF interruption [3] and the data is obtained for SLF interruption from the development stage of 300 kV GCB by the equation (1) expressed the relation among dv/dt, p, di/dt.

$$dv/dt = kp^{\alpha}(di/dt)^{-\beta} \quad \cdots\cdots (1)$$

where $\alpha = 1.6$, $\beta = 2.4$ [6]

The necessary pressure rise remains more than 10 ms of arcing time by calculation in Fig.5. This breaker was expected to interrupt 63 kA-50 Hz 90%SLF condition for more than 10 ms.

Interruption tests are conducted by synthetic test. Pressure rise in the puffer cylinder is measured and the results are indicated in Fig. 5 together with its success and failure. ○ represents success and ● does failure. It is confirmed that the breaker with model B can interrupt with the higher pressure than the predicted value and interruption window of more than 10 ms. The measured pressure rises at current zero are mostly coincide with the calculated ones, which indicates the evaluation by the calculation is reasonable.

4. BTF Interruption Capability

Breaker terminal fault (BTF) condition of 100% symmetrical current (T100s) and asymmetrical current (T100a) are investigated where the current is the highest and which has great influence to the energy to be disposed and to driving energy. Especially in T100a with major loop (T100a-Ma) which has large current in last half cycle, the driving energy will be critical. Typical two cases of on load opening condition are calculated for model B. One is for the longest arcing time for IEC standard on this GCB. Another is for the possible shortest arcing time considered from the longest arcing time (23.8 ms) and a duration time of minor loop (7 ms). Subtracting 7 ms from 23.8 ms, we assumed the value is approx.17 ms. In Fig. 6 which shows each calculation result, pressure-rise on arcing time 17 ms is slightly higher

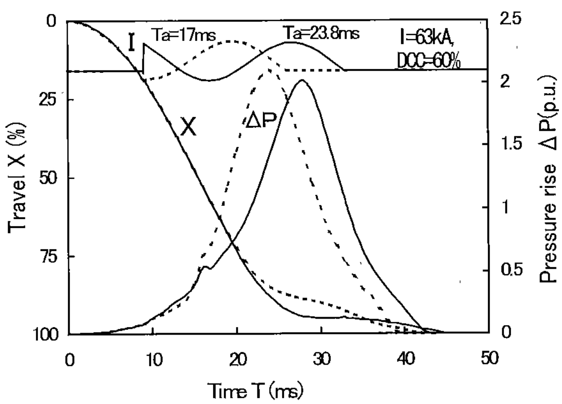


Fig. 6. Calculated opening characteristics on T100a major loop interruption

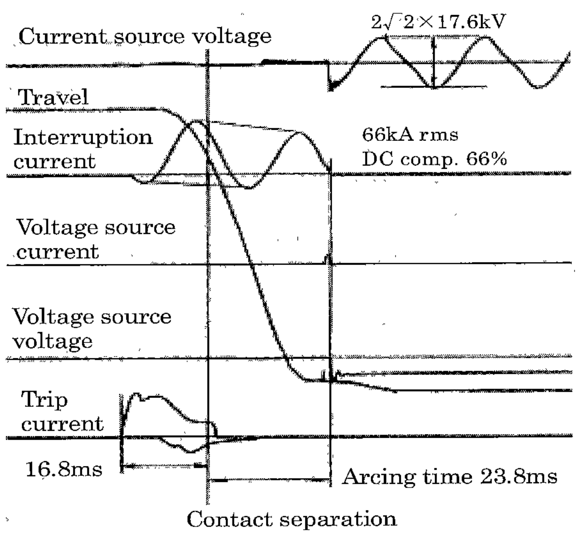


Fig. 7. Oscillogram of T100a major loop interruption

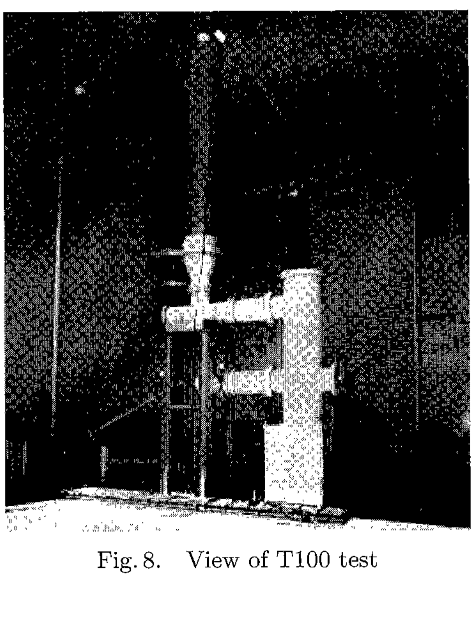


Fig. 8. View of T100 test

than that on arcing time 23.8 ms. However, the longer the arcing time is, the more the travel stays in this breaker. Even in the case of the longest arcing time, travel somewhat stays near the end but does not go reverse, which allows us to consider it has sufficient driving energy. The interrupting tests for T100s and T100a are conducted. An oscillogram with the longest arcing time in T100a-Ma is shown in Fig. 7. With respect to travel, this shows good agreement with calculated result and no reverse travel. Fig. 8 shows the test view for T100.

5. Operating Mechanism and Mechanical Test

Choice of driving mechanism is one of the most important points for developing circuit breaker. We considered that it could be the best way from reliability and cost point of view choosing existing 300 kV class hydraulic driving unit which has been supplied from 1982 for more than 4000 units, only modifying by extending its stroke.

Minimizing moving mass is necessary to achieve that. The target is to reduce the moving mass down to 70% compared to existing 300 kV-63 kA GCB so as to increase opening velocity by 20% with the driving energy of 20% higher than that of the present one. The very detail calculation of mass and its mechanical strength for each part lead to the target and the before mentioned pre-series breaker is manufactured using model B. Stress measurement is conducted for principal positions of the breaker and all the results are confirmed within the tolerance. 10,000 times of mechanical operation is conducted for confirming sufficient mechanical capability.

6. Type Test for CB

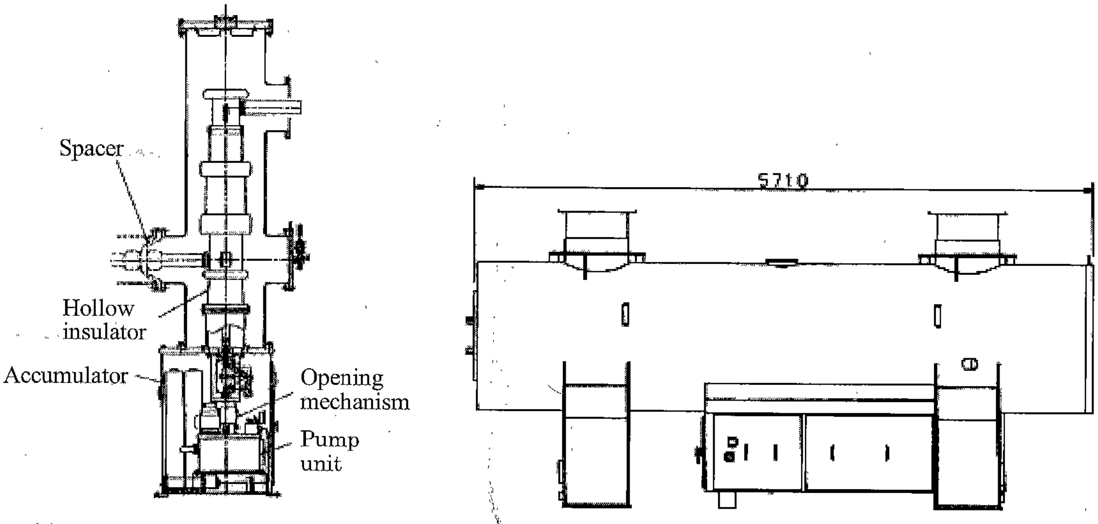
Construction of the circuit breaker for the type test is shown in Fig. 9(a). All the type tests are conducted according to the IEC standard. Interruption tests are successfully done in the international neutral test station in Europe and we have got the certificate. Other items such as temperature rise, mechanical operation, dielectric performance and so on are also successfully carried out under the witness of the third party.

7. GIS Application and its Influence

Fig. 9 also shows comparison of this single break 420 kV-63 kA GCB and same rating existing 2-break GCB in same scale. As shown in Fig. 9, significant reduction is achieved with respect to out-shape dimension. The volume and weight in new GCB are 19% and 29% respectively comparing with existing GCB. This single break GCB does greatly contribute to the reduction of GIS and substation. Fig. 10 shows the GIS layout with one and a half CB scheme in comparison between with the existing two break breaker and with the developed single break breaker. The latter requires only 46% in installation area compared with the former one.

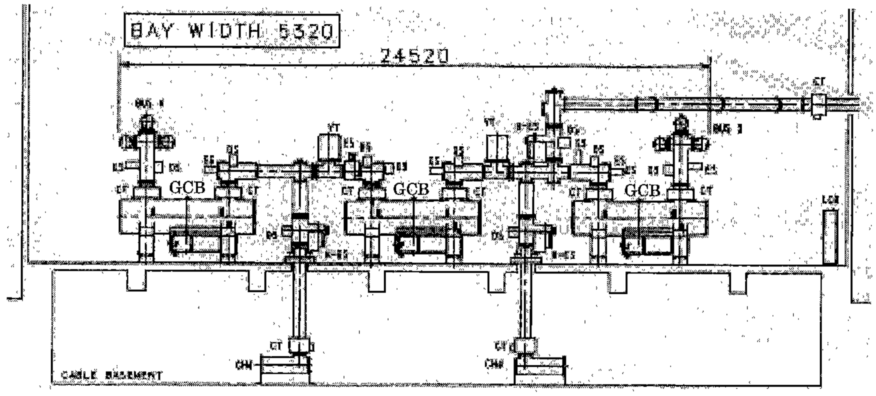
8. Discussion

8.1 Interruption Capability and Driving Energy Reducing the driving energy is very important

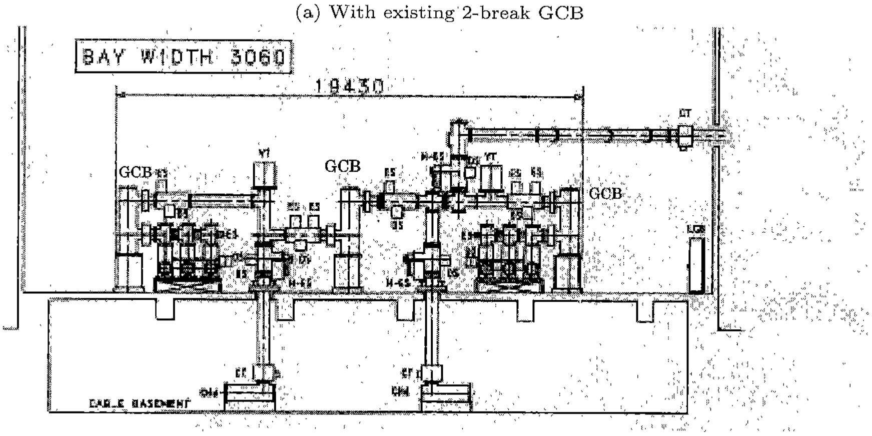


(a) Construction of new 1 break GCB (b) Outline of existing 2 break GCB

Fig. 9. Comparison of 420 kV-63 kA new and existing GCB



(a) With existing 2-break GCB



(b) With 1-break GCB

Fig. 10. Comparison in GIS layout for 420 kV $1 \cdot 1/2$ scheme

for the developing circuit breaker, because smaller driving energy allows to make the moving parts thin therefore light weight, especially connecting rod and insulating operating rod. Furthermore supporting part can be simplified by reducing mechanical rigidity on the supporting part for moving side. All result in reducing manufacturing cost.

Principal items to determine driving energy of puffer type circuit breaker are opening velocity, moving mass and reacting force caused by ΔP in puffer cylinder with large current interruption. The opening velocity for high voltage breaker will be mainly determined by the capacitive current interruption capability, which can be minimized by optimizing the electric field strength between the contacts and controlling the pressure around the top of fixed arc contact during opening operation. To minimize moving mass should strongly concentrated in designing within mechanical strength because it contributes significantly for minimizing driving energy.

The necessary ΔP can be determined by 90% SLF interrupting capability. The amount of arc energy acquisition inside of puffer cylinder [3] and principal dimensions like diameter of puffer piston should be defined so that the necessary and sufficient pressure for the duty can be obtained for necessary arc duration. The next step is to determine the minimum driving energy so that the travel will not be back as long as interrupting capability for T100a, which will produce the highest reactive force by ΔP for interruption, is not affected.

We confirm that this 420 kV-63 kA single break breaker with model B can produce necessary pressure for 90% SLF interruption and it has sufficient driving energy for T100a interruption. The driving energy is 55% and its moving mass is 28% in comparison with our existing two break breaker for 420 kV-63 kA.

8.2 Review on Other SLF Interruption Capability This breaker also covers the rating of 50 kA-60 Hz together with 63 kA-50 Hz. We investigate the capability by the equation (1), severity for 50 kA-60 Hz 90%SLF is 90% of that of 63 kA-50 Hz case. But taking decrease of the pressure rise in puffer cylinder caused by smaller current into account, the severity can be estimated similar. We confirm this breaker has sufficient interruption capability with good interruption window for 50 kA-60 Hz 90% SLF by the test.

9. Conclusion

420 kV-63 kA single break GCB has been developed. Firstly minimum-opening velocity was determined by the electric field calculation on contact parts of interrupting chamber, optimization around the nozzle part with the pressure measurement at the top part of fixed arc contact.

Secondly small driving mechanism was proved to be possible to use for this breaker with suppressing driving energy by minimizing moving mass, and pre-series breaker was manufactured.

Thirdly the necessary pressure rise in puffer cylinder with necessary arc duration was obtained with the breaker for 90%SLF interruption capability. Then T100a interruption test was conducted with the driving energy determined from the above steps and confirmed this breaker had enough capability without any reverse travel.

Type tests were carried out for the breaker for actual production at the international neutral test station according to IEC standard and we got the certificate.

The installation area for the GIS layout can be reduced by 46% with this single break GCB in case of one and a half breaker scheme compared with our existing two break GCB.

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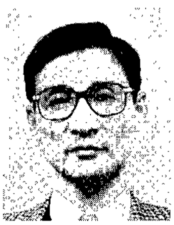

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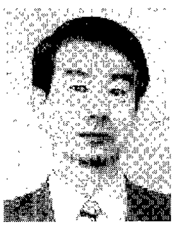

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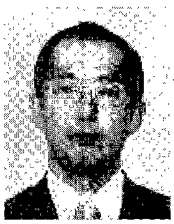

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