Current Status and Future Trend of Controlled Switching System

Author: *Hiroki Ito**

1. Introduction

Life-cycle cost reduction of transmission and distribution systems is becoming increasingly important to adapt to global changes resulting from factors such as electricity market liberalization, electricity industry deregulation, environmental protection issues, as well as various emerging technologies developed using information technology advances.

Technical requirements for power equipment have also been changing. For instance, the development of high-voltage and large-capacity equipment has advanced to ensure stable power supply in the context of growing electricity demand. However, the most important requirement in this period of severe competition brought about by liberalization and deregulation is to develop more reliable and cost-effective equipment.

As emerging technologies such as controlled switching, remote monitoring diagnostic techniques and digital controls became practical, CIGRE (International Council on Large Electric Systems) have conducted extensive investigations on field experience of these technologies as well as international surveys on the reliability and maintenance practices of high voltage equipment. In the 1990s, market demands for extending the life while reducing life-cycle cost drove research and development towards further compactness, reliability and reduced operating energy. These efforts led to the 550kV one-break gas circuit breaker (GCB) and the 1100kV two-break GCB.

Controlled switching has become an economical substitute for a closing resistor and is commonly used to reduce switching surges. The number of installations using controlled switching has increased rapidly due to satisfactory service performance since the late 1990s. Currently, it is often specified for shunt capacitor and shunt reactor banks because it can provide several economic benefits such as elimination of closing resistors and extension of a maintenance interval for nozzle and contact. It also provides various technical benefits such as improved power quality and suppression of transients in transmission and distribution systems. Recently, an advanced controller considering the residual flux in a transformer core has been installed and has demonstrated good performance in the field. This controller can significantly suppress overvoltage induced by inrush currents in case of transformer energization and allows more flexible operations in accordance with load change of electricity.

IEC62271-302 TR, including the testing requirements and procedures for controlled switching of GCBs, will soon be issued and will clarify the required characteristics for both newly installed and existing GCBs resulting in a further increase of applications.

An IEC62271-302 Technical Report titled 'High Voltage Alternating Current Circuit-breakers with Intentionally Non-simultaneous Pole Operation' will be issued shortly in 2007, which includes the testing requirements and procedures for controlled switching and clarifies the required characteristics for both newly installed and existing GCB resulting in further increase of applications.

2. Installation Records of Controlled Switching in Service

According to the CIGRE survey (Figure 1), approximately 2,400 controlled switching systems (CSS) were supplied and installed around the world in 2001, and more than 4,000 units are now estimated to be in service. Before 1995, the number of installations was limited because of technological immaturity, but the number has increased rapidly since the late 1990s when effective compensation algorithms became available using advanced sensors and reliable digital relay technologies. Currently, about 70% of the installations worldwide are applied to capacitor banks, but in Japan controlled reactor opening is the most common application. No CSSs are used to shut capacitors in Japan

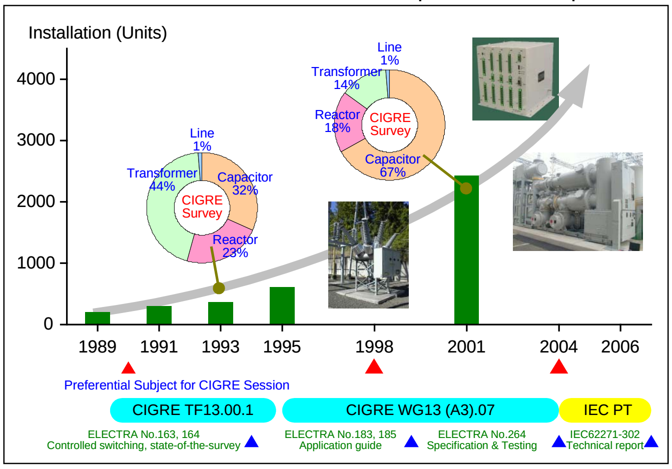

Fig. 1 CIGRE survey on installation records of controlled switching in worldwide service

**Transmission & Distribution System Center*

Japan because an installation of fixed inductors can suppress the magnitude of inrush currents, which are originally intended to reduce the 5th harmonics of the power frequency.

CIGRE has investigated technical trends of CSS in detail. First it installed TF 13.00.1 and published a general view of the features and feasibility of CSS(1) in 1995. TF was transferred to new Working Group 13.07 and an application guide to CSS(2) was published based on an international survey of field experience in 1999 and proposed testing requirements and procedures(3) in 2001. The guide emphasizes the importance of compensating for the variations of operating time because a CSS requires accurate operation consistency during the lifetime of a circuit breaker. Variations of operating times due to operating conditions such as ambient temperature, control voltage and stored energy of the drives can be compensated by the controller using the measured dependence of variations of operating times on these conditions. The operating time should also be compensated to account for the deviations of the operating time caused by aging due to repeated operations and the first operation after a long idle time. Recent research has revealed that the closing time for some hydraulic operating mechanisms was significantly delayed after idle times of only a few hours(3)(4). Accordingly, idle time compensation is essential for even a CSS that is operated daily.

In accordance with the need for flexible operation and control of switching equipment in a transmission and distribution system, advanced controllers capable of controlled transformer energization considering the residual flux in the transformer core(5) and for controlled re-closing of uncompensated lines(6) have been demonstrated to be effective in suppressing switching transients in the field. Further development efforts will increase the number of installations of CSS for these applications.

3. Principles of Controlled Switching

CSS is composed of an independent-pole-operated circuit breaker, controller and sensors that measure system voltage, current through the breaker, ambient temperature and operating pressure of the drives (if required).

The term CSS refers to the technique of controlling the timing of the pre-strike (for close operations) or contact separation (for open operations) for each pole of a circuit breaker with respect to the phase angle of the system voltage or the current in order to minimize stresses on the components of the power system.

The schematic timing sequence for energization at a pre-determined phase angle is shown in Figure 2. The randomly issued closing command is delayed by an appropriate amount of time by the controller based on a calculated closing time for the next operation and a known pre-arcing time so that current is initiated at the target phase angle. The optimum instant for making differs according to the switching application as well as the breaker performance. Figure 3 summarizes major switching problems and their solution by CSS for various applications.

4. Applications

4.1 Capacitive and inductive switching

Energization of shunt capacitor banks causes high amplitude inrush currents and an associated overvoltage in the local substation and a remote overvoltage at the receiving end of transmission lines connected to the substation. A modern GCB generally provides a very low probability of restrike for capacitive current interruption. Nevertheless, the probability of restrike can be further reduced by means of CSS, which ensures long arcing times which are especially effective for GCBs with several fault current interruptions.

Controlled closing of shunt capacitor banks is used to minimize stress on the power system and its components. It also provides economic benefits such as elimination of a pre-insertion resistor or a fixed inductor and extension of the number of allowable operations before the nozzle and contacts of the GCB need to be replaced.

All circuit breakers exhibit a high probability of

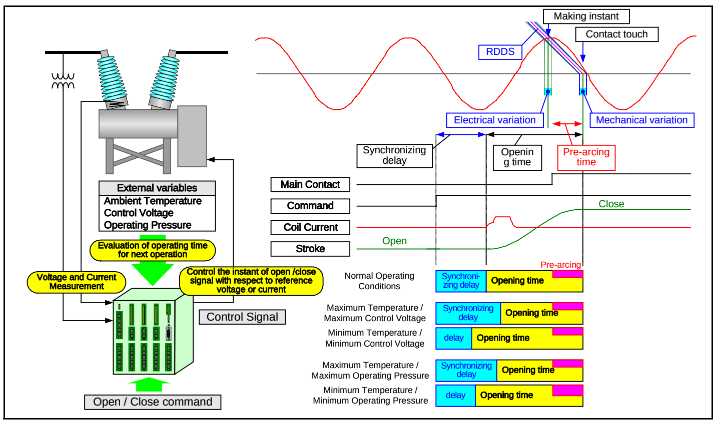

Fig. 2 Schematic closing sequence and compensation of operating time varied with external conditions

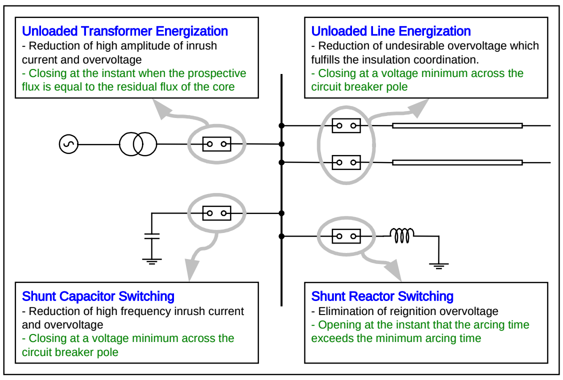

Fig. 3 Switching problems and solutions

reignition during de-energization of shunt reactors for arcing times of less than a minimum arcing time. Controlled opening can avoid reignition overvoltages by separating the contact when the arcing time will be longer than the minimum arcing time while considering the relative importance of chopping overvoltage, which increases with an increase in arcing time. Since reignition overvoltages are normally more severe than chopping overvoltages, it is a common practice in CSS applications to increase the arcing time.

Small inductive current interruption phenomena can be classified into three categories as shown in Figure 4. These depend on the contact gap at the instant of current interruption: (a) Reignition-free as a result of interruption success because the dielectric withstand between the contacts always surpasses the transient recovery voltage after the interruption, (b) Reignition as a result of dielectric breakdown, and (c) Thermal reignition as a result of thermal interruption failure. Thermal reignition, however, does not cause any significant transients and can be successfully interrupted at the next current zero. Accordingly, the periods of reignition-free window (a) and thermal reignition window (c) can be chosen as the opening target.

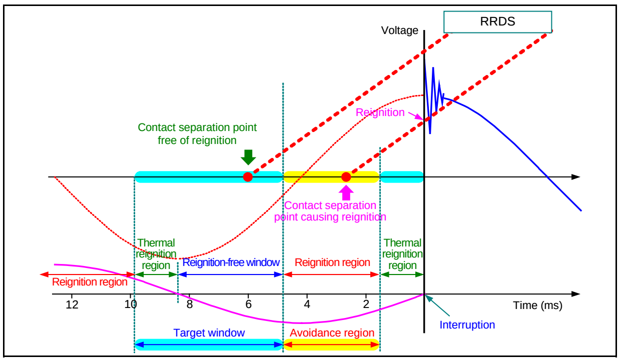

Fig. 4 Controlled reactor opening for preventing reignition free

Controlled opening of shunt reactor banks can eliminate the reignition overvoltage, which has the potential to induce damage to the GCB such as nozzle puncture. It also provides economic benefits such as reduced possibility of damage to the reactor and extension of the number of operations before the nozzle and contact need to be replaced by more than a factor of two relative to that required for a GCB without CSS.

4.2 Unloaded transformer energization

Transformer energization can create high-amplitude magnetizing inrush currents of up to several thousand Amperes and a temporary overvoltage depending on the energizing instant. These transients degrade the power quality and may cause false operation of protection relays. High inrush currents also impose severe electrical as well as mechanical stresses on the transformer windings and may reduce the life expectancy of a transformer exposed to frequent energization in the over-loaded condition.

Energization of a transformer with no residual flux in a core at peak voltage will cause no transients. However, the flux changes depending on the de-energization instant, and a random energization may generate greater saturation of the magnetizing currents. Therefore, the optimum targets should be adjusted taking into account the residual flux. The inrush current can be eliminated by energization only when the prospective normal core flux is identical to the residual flux. (See Figure 5.)

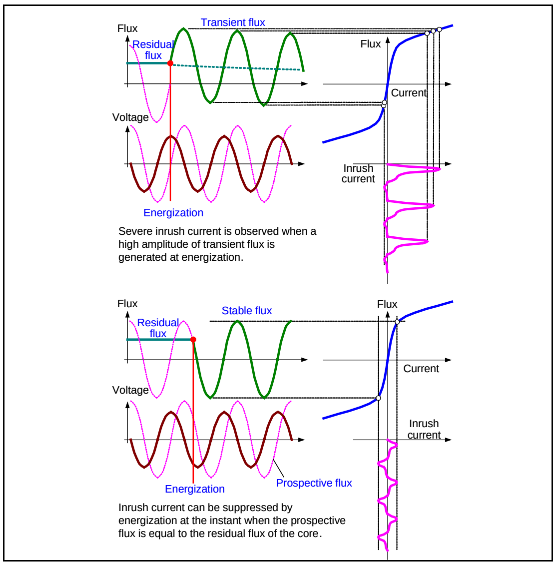

Fig. 5 Magnetizing flux in a core of a transformer and corresponding magnetizing current

The innovative residual flux measurement was developed and its accuracy proven in the field by integrating the voltage waveform after de-energization of the transformer as well as any CB operations in case of fault clearing connected to the system. It was incorporated into a commercial controller, which has already demonstrated good performance in several field applications.

4.3 Uncompensated and compensated line switching

Energization and auto-reclose of long transmission lines can cause undesirable overvoltages in the transmission network, so special overvoltage mitigation measures are employed to meet the insulation coordination considerations. The most common practice has been to use metal-oxide surge arresters which are often combined with closing resistors to improve reliability, but this approach is expensive.

CSS can potentially reduce the re-closing transients and further improve the reliability of restrike-free performance. It can also provide economic benefits such as elimination of closing resistors and reduction of the insulation level for surge arresters and transmission towers. For line applications, a circuit breaker with a higher normalized RDDS (Rate of Decay of Dielectric Strength) is generally preferable although the operating scenario and targeting strategies should be studied thoroughly. Idle time compensation is essential for drives whose operating times have this dependence. The strategies for different line configurations are described below.

a) In the case of an uncompensated line with an inductive potential transformer, the controller can suppress the transients effectively (less than 1P.U.) by controlled closing at voltage-zero on the source-side because the trapped DC charge is rapidly discharged (typically less than 100ms). (See Figure 6.)

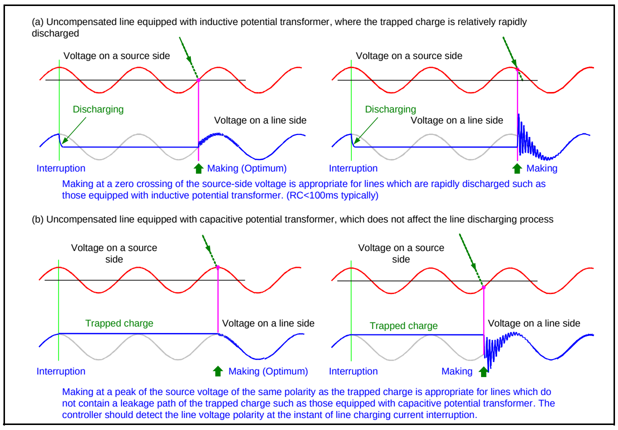

Fig. 6 Optimum making targets for unloading line controlled switching

b) In the case of an uncompensated line with a capacitive potential transformer, no leakage path exists for the trapped charge. The optimum target is the voltage peak on the source-side of the same polarity as the trapped charge.

c) In the case of a compensated line, the degree of compensation has a significant effect on the line-side voltage. The voltage across the breaker shows a prominent beat especially for a high degree of compensation because the line oscillation frequency typically falls in the range of 30–50 Hz. The optimum instant is the voltage minimum across the breaker, preferably during a period of minimum voltage beat(6) as shown in Figure 7.

5. Conclusions

The rapid increase of CSS applications is ascribed to several factors, such as successful field experiences of the systems with an effective compensation algorithm, the CIGRE proposal for type testing recommendations, and versatile operations and controls of transmission systems due to global changes in the electrical industry. Since CSS can provide significant technical and economic benefits, including enhancement of power quality and operational flexibility, it could be incorporated into circuit breaker control systems as a standard specification in the near future.

As information technologies progress, it may become possible to use CSS for fault current interruption, uprating of modern and aged circuit breakers, and compensated line auto-reclose with minimum surge-arresters. Furthermore, various monitoring results of GCBs recorded in the controller can be used for remote diagnostics and condition-based maintenance in order to improve equipment reliability and optimize maintenance practices.

References

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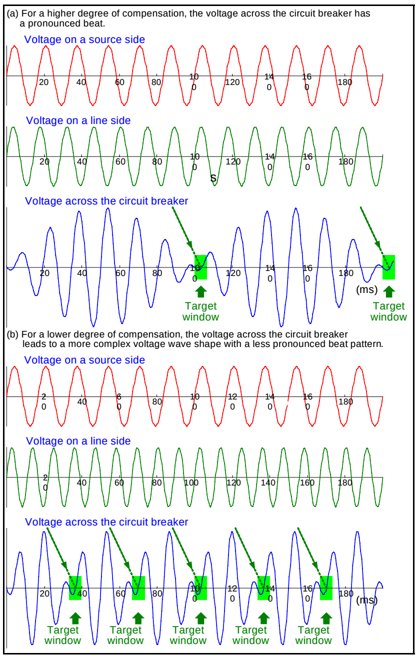

Fig. 7 Optimum making target for compensated line