# Control Algorithm of Controlled Switching System

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The effect of controlling high-magnitude voltage and current transients in controlled switching systems largely depends on the prediction accuracy of the operating time. This paper explains the operating principle of Mitsubishi's controlled switching systems and details the method for predicting the operating time based on environmental conditions, previous operating times and idle time. It also describes the results of validating the effectiveness of the method.

## 1. Operating Principle of Controlled Switching System

The operating principle of controlled switching systems is described using Fig. 1 "Block Diagram" and Fig. 2 "Timing Chart", both of which represent an example of controlled closing.

In controlled closing, the timing of mechanical contact touch (closing) for establishing electrical connection (making) between the contacts of the circuit breaker is controlled in a particular phase of system voltage. The function consists of the following steps:

(1) The target closing phase is determined taking into consideration the electrical characteristics and scattering in mechanical operation of the circuit breaker and the load-side conditions.

(2) The next closing time (time between input instant of the controlled closing command and the instant of closing) is predicted based on environmental conditions and previous operating times.

(3) The delay time is calculated and set in the timer. The delay time refers to the difference in time between the target closing phase minus the predicted

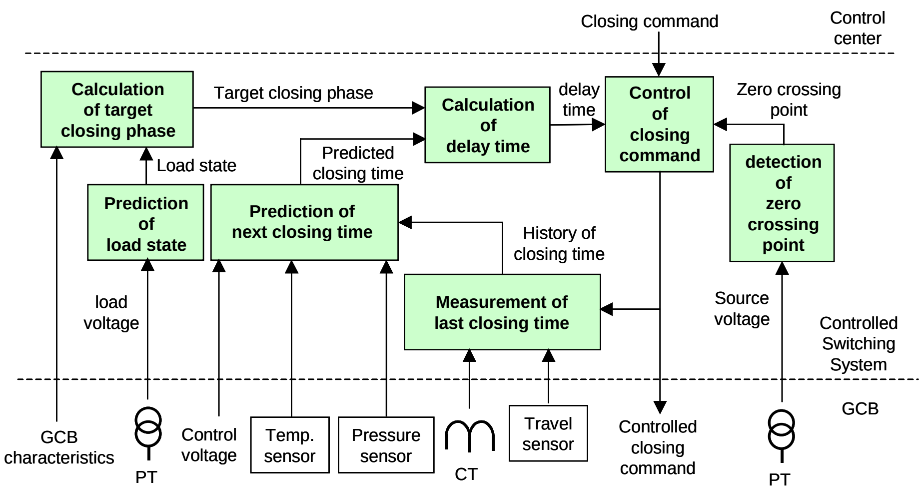


**Fig. 1 Block diagram of controlled switching system (controlled closing)**

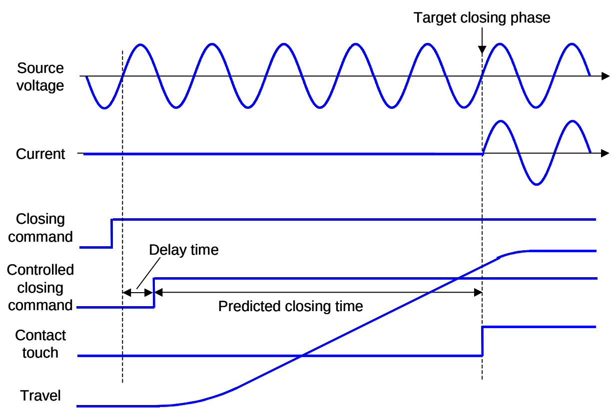


**Fig. 2 Timing chart of controlled closing**

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closing time and the latest zero-crossing point.

(4) With the closing command input, the zero-crossing point is detected to start the timer. After the elapse of the delay time, the controlled closing command is output to start the closing operation of the circuit breaker.

(5) After the elapse of the closing time, the circuit breaker is closed. The actual closing time is measured from the main circuit current or travel sensor, which is then reflected in the prediction of the next closing time.

## 2. Prediction Methods of Operating Time

### 2.1 Outline of prediction method

Since control is performed by the method described above, the circuit breaker is operated at a different timing than the optimum switching target when the real operating time deviates from the predicted operating time. To improve control accuracy, it is essential to predict the next operating time precisely.

The central value of the circuit breaker operating time changes with such factors as the control voltage, ambient temperature, operating pressure, contact wear from accumulated operations, long-term aging, idle time, intrinsic properties, etc. [1] [2] The predicted operating time is obtained by Eq. (1) below, with the average operating time $T_{std}$ under normal environmental conditions compensated as shown in (a) through (c).

(a) Compensation time based on environmental conditions: $\Delta T_{env}$

(b) Compensation time based on previous operating times: $\Delta T_{const}$

(c) Compensation time based on idle time: $\Delta T_{idle}$

$$\text{Predicted operating time} = T_{std} + \Delta T_{env} + \Delta T_{const} + \Delta T_{idle} \qquad (1)$$

Each compensation time mentioned above is described in detail below.

### 2.2 Compensation based on environmental conditions

Figure 3 shows an example where the difference between the average closing time measured under each condition for the control voltage and ambient temperature and $T_{std}$ are plotted in a two-dimensional rendering. The shape of the control voltage vs. operating time curve may differ within a high- or low-temperature range as shown in the figure, depending on the type of circuit breaker. From a practical viewpoint, it does not appear to be a problem to consider the dependency of the operating time on the control voltage and ambient temperature is independent when the variation width of the environmental conditions is small; however, it appears necessary to involve a two-variable function when the variation is expected to become comparatively large. So, compensation time functions in the form of a two-dimensional map as shown in Fig. 3 are prepared in advance for both opening and closing. This map can be used for common variation characteristics applicable to the same types of circuit breakers.

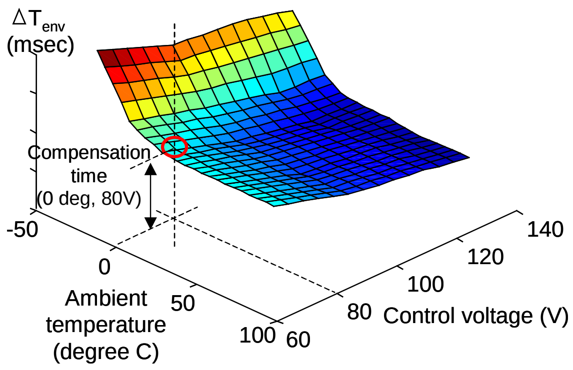


**Fig. 3 Environmental compensation time map**

During practical use, the compensation time $\Delta T_{env}$ is calculated by monitoring the control voltage and ambient temperature sequentially by means of the sensor installed in the circuit breaker and interpolating the two-dimensional map. In the case of a hydraulic- or pneumatic-operated circuit breaker, the operating pressure is further monitored and compensation is applied using the two-dimensional map of operating pressure and ambient temperature.

### 2.3 Compensation based on previous operating times

For the compensation based on previous operating times, it is necessary to know the precise operating times during actual use. Accordingly, the operating time is calculated based on the main circuit current for closing and travel sensor signal from the contact of the circuit breaker for opening. The operating time $T_{meas}$ of each operation is measured, and then the compensation time $\Delta T_{const}$ is calculated by Eq. (2) below based on the previous 10 operating times for opening and closing, respectively.

$$\Delta T_{const} = \Sigma w(n)\{T_{meas}(n) - (T_{std} + \Delta T_{env}(n) + \Delta T_{idle}(n))\} \qquad (2)$$

where n is an integer of 0 through 9 and w(n) is the weighting coefficient. The weighting coefficient is specified so that the data of an immediate operation is heaviest and the sum is 1.

### 2.4 Compensation based on idle time

The central value of the next operating time may fluctuate with the idle time, which is the time interval between the last operation and next operation, depending on the type of circuit breaker. So, the variation in average operating time based on idle time is measured in advance and the relationship between idle time and compensation time is rendered in the form of a map. This map can be used for common variation characteristics applicable to the same types of circuit breakers.

During practical use, the compensation time $\Delta T_{idle}$ is updated sequentially by checking the map in accordance with the elapsed time from the last operation of the circuit breaker.

## 3. Test Results [2]

### 3.1 Controller test

To confirm the function of a controlled switching system, a test was conducted using a GCB simulator. Control error was checked by inputting operating commands at random moments with the optimum target instant fixed. The control error under the condition that no noise is contained in the voltage or current signal, was approximately $\pm 10$ μsec.

### 3.2 No-load operation test

Next, a no-load operation test using a 145-kV/40-kA spring-operated gas circuit breaker was conducted to evaluate the control accuracy of the system in combination with a circuit breaker with respect to the variation in environmental conditions. AC 125 V as the standard control voltage was applied to the main circuit. Figures 4 and 5 show the control error when the ambient temperature was changed between −30°C and +60°C, with the control voltage maintained at a fixed level. The average error is plotted on the left side of the figures. The upper and lower bars indicate the standard deviation of the errors. The right side in the figure indicates the error distribution in the entire measurement.

The target instant was set at an electrical angle of zero degrees. The results show that control errors have a normal distribution around zero regardless of the variation in ambient temperature; proper controlled switching without steady-state error appears to have been made. The same result was obtained in the test with the control voltage changed.

Since the standard deviation of errors under the respective operating conditions almost agrees with the scatter of operating time, most of the factors behind the generation of control error under the same environmental conditions may be attributed to the mechanical operating scatter of the circuit breaker itself. Since the standard deviation, σ, for combination with this circuit breaker is 0.5 msec or less to meet the permissible operating scatter of ±1.5 msec for 3σ, which is a guideline of CIGRE [1], it can be concluded that the performance is sufficient for controlled switching.

Figure 6 shows the predicted errors (closing) when operated a number of times under the condition that the control voltage is maintained at a fixed level and the temperature is maintained at room temperature (DC 125 V, 10–30°C). The errors before and after applying compensation based on previous operating times are compared in the figure. Since the central value of closing time changes with long-term aging, the steady-state error increases with an increase in the number of operations when no compensation is applied. This means that control is performed without steady-state error by applying compensation based on previous operating times. The same trend was confirmed with controlled opening.

We intend to conduct further studies on expanded application ranges, improvement of control accuracy, and faster control algorithms.

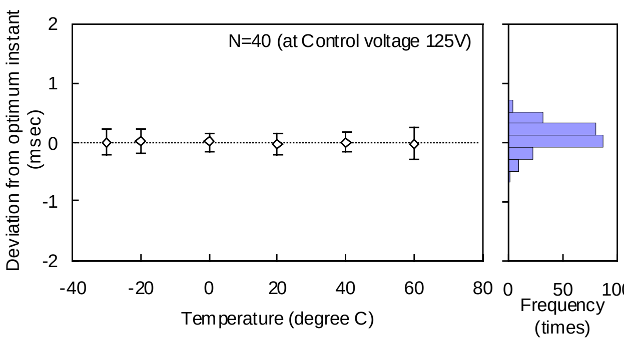


**Fig. 4 Variation of controlled opening instants for different temperatures**

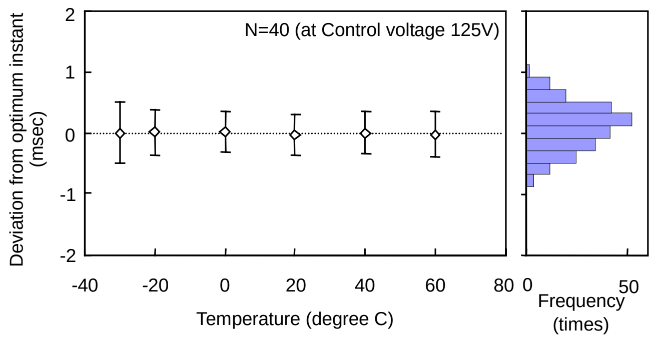


**Fig. 5 Variation of controlled closing instants for different temperatures**

**References:**

(1) CIGRE Working Group 13.07, "Controlled Switching of HVDC Circuit Breakers – Guide for Application," Part 1: Electra, No. 183, pp. 43-73, 1999, Part 2: Electra, No. 185, pp. 37-57, 1999

(2) H. Tsutada, T. Hirai, H. Kohyama, H. Ito and K. Sasaki, "Development of Synchronous Switching Controller for Gas Circuit Breakers," Proceedings of IEEE Power Engineering Society Transmission and Distribution Conference, Vol. 2, pp. 807-812, 2002


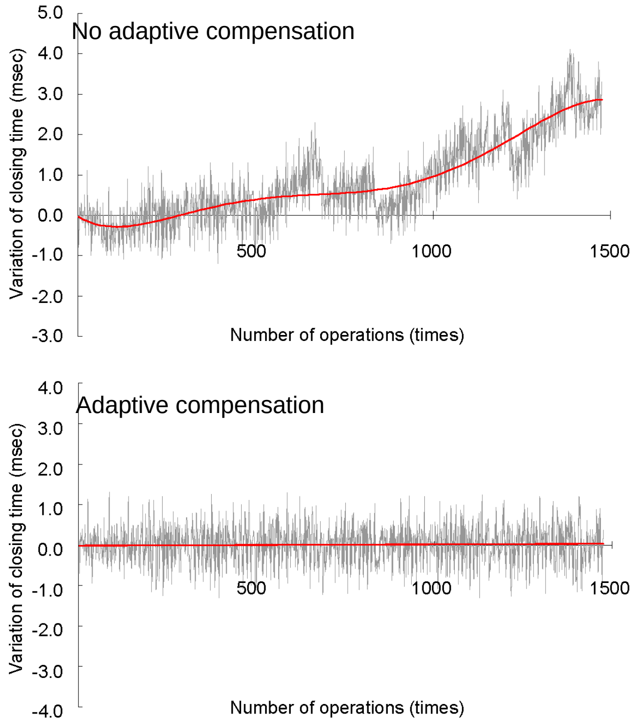


**Fig. 6 Effect of adaptive compensation**