DEVELOPMENT OF MV SYNCHRONOUS CIRCUIT BREAKER

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ABSTRACT

High voltage synchronous circuit breakers (SCBs) have been widely accepted as a promising solution for reduction of switching surges. It is essential for SCBs to keep the operating times consistent or predictable over their service life. Extensive investigations have been made on the operating parameter dependency on operating times such as control voltage, stored energy of the drive (hydraulic pressure/spring load) and ambient temperature, etc.

Although MV SCB has been developed based on the permanent magnetic actuators, studies on the operating time dependencies for MV SCBs driven by permanent magnetic actuators are still limited. A 40.5kV VCB with 3 independent poles driven by 3 individual permanent magnetic actuators has been developed. A synchronous control unit (SCU) has been developed as well based on a MCU system. A new MV SCB has then been developed by the combination of both. Temperature dependency of operating time for the newly developed SCB has been investigated, the measured result shows, for the permanent magnetic actuators the operating time is irrelevant with the ambient temperature. Tests have been carried out on the capacitor bank switching with the developed SCB, the testing results show the satisfied performance of the SCB in respect of the reduction in the inrush currents as well as the reduction of the over voltages.

1. INTRODUCTION

Vacuum circuit breakers (VCBs) have been extensively used in MV distribution networks due to their excellent performance, but VCBs have their own limitations as well. For instance, during the energization of capacitor banks, if the voltage across the contacts is not zero in the moment when they get touched inrush currents with high frequency and large amplitude will occur. Theoretically, the maximum amplitude of the inrush current can reach more than 50 times that of the steady current [1]. On the other hand, during the deenergization of the capacitor banks, over voltages are likely to occur due to the high probabilities of re-strikes.

Presently, the most common solutions to restrict the operating surges in practice are the pre-insertion of resistors or inductors and the application of surge arrestors. One of the effective and economic solutions for this kind of problems is the use of the synchronous switching or so called point-on-wave switching technology which makes the contacts of a circuit breaker close or open on the particular instants in relevant to the sinusoidal waveform of the voltage/current, to avoid inrush currents and over voltages.

In case of the energization of shunt capacitor banks, when making at voltage zero, the inrush current can be greatly reduced. Theoretically the amplitude of the inrush current has only 1.6 times that of the rated current. During the deenergization of the shunt capacitor banks, the re-strike probability can be drastically minimized as long as longer arcing time i.e. longer contact gap in the instant of arc extinction can be guaranteed.

A synchronous circuit breakers is an ordinary circuit breaker with 3 dependent poles equipped with an electronic device (a controller) which can operate (open or close) at a predetermined point in relation to the network reference signals. Early synchronous circuit breaks (SCBs) revealed mainly in the transmission levels[2][3][4]. Recently with the development of the permanent magnetic actuators, SCBs began to reveal in the medium voltage levels[5][6]. A synchronous control unit (SCU) has been developed on the basis of micro controller PIC16F877. A 40.5kV synchronous circuit breaker was developed by embedding the SCU to a 3 pole independent vacuum circuit breaker driven by 3 individual permanent magnetic actuators. Tests have been carried out on the capacitor bank switching with the developed SCB, the testing results show the satisfied performance of the SCB in respect of the reduction in the inrush currents as well as the reduction of the over voltages.

2. CONFIGURATION OF THE MV SCB

The MV SCB described in this paper consists of a synchronous control unit (SCU) and a 40.5kV vacuum circuit breaker with 3 independent poles driven by 3 individual permanent magnetic actuators respectively.

(1) VCB with permanent magnetic actuators

Permanent magnetic actuators are more reliable and have better consistency than other types of mechanisms, say spring type, due to their simple structure.

Permanent magnetic actuators are the most proper mechanisms for MV SCBs. The proposed SCB consists of a 40.5kV VCB driven by 3 independent permanent magnetic actuators, shown in figure 1[7], and a synchronous control unit (SCU) which will be described in the next section.
(2) Synchronous Control Unit (SCU)

1) Architecture of the SCU

The operation energy of the permanent magnetic actuator is stored in a capacitor bank, which is keeping charged to a specified voltage level all the time. During the operating, the stored energy is released to the opening/closing coil of the mechanism via IGBTs. The opening/closing operation is therefore accomplished by releasing the electric energy from the capacitor bank to the opening/closing coils of the magnetic actuator via IGBTs.

The synchronous control unit is based on a microcontroller PIC16F877, which is a typical SOC (system on chip) MCU. Its instruction cycle is only 1µs, which is far enough for the control of the power frequency SCBs.

The architecture of the SCU is shown in figure 2. The capacitor bank is keeping charged by an AC/DC module, which converts 220V AC or DC voltage to a stable DC voltage with a specific value. The system voltage/current is transformed by the primary PT/CT to 100V/5A. This secondary voltage/current signals are further transformed by the SCU to lower voltage signals. After the voltage comparator module, the sinusoidal signals are converted to square waves further transformed by the SCU to a low voltage signals, with their rising and falling edges in relevant with the zero crossings of the voltage/current. Therefore, by capturing these rising/falling edges, the SCU, the zero crossings of the system voltage/current can be located by the SCU. The positions of the actuators are detected by 6 approximate sensors which indicate the opened/closed positions of the 3 poles of the breaker.

An individual permanent magnetic actuator consists of two coils, one for the open operation, and the other is for the close operation. When current flows in one coil, the induced current may occur in the other coil due to the inter-induction effects of the two coils. This may greatly reduce the efficiency of the mechanism, this phenomena is avoided by the optimized design of the topology of the IGBT array.

2) Control Strategy of the SCB

The arcing time of the SCB can be adjusted by the controlling of the opening operation. Similarly, making instant of the CB can be controlled by the SCU as well, especially, during the capacitor bank switching, making at voltage zero of the CB can be achieved which can effectively minimize the inrush current.

For controlled switching of a capacitor bank, the principle of the controlled closing is to close a phase, when the voltage across it is zero, while the controlled opening facilitates current interruption with a relatively larger contact gap, i.e. small arcing times are avoided, therefore re-strike probabilities can be remarkably reduced.

For the neutral floating system, two phases (phase B and C) are closed simultaneously at the corresponding phase to phase zero voltage. The third phase (Phase A) is then closed 90 electrical degrees later at the following phase to earth voltage zero crossing.

Accordingly, one can get the controlled opening sequence of the SCB for capacitor bank switching for the neutral unearthed system. In this case, long arcing times should be guaranteed by the operation strategy for all the 3 poles of the CB

3. FACTORS INFLUENCING THE OPERATION TIMES OF THE SCB

The SCB can make the contacts close/open on any desired phase in relevant with the voltage/current signals as long as the operation time is predicted. Hence the prediction of the operation time plays a very important role for the proper operation of the SCB. The operation time of SCBs can be influenced by many factors, therefore one of the most important functions of the SCB is to predict the operation times accurately, considering all the influencing factors.

(1) Influence of the control voltage

The operation energy of the permanent actuators is stored in the energy stored capacitor bank with very large capacitance. During the open/close operation, the stored electrical energy is released into the open/close coil of the mechanism. The opening/closing speed, i.e. the opening/closing time of the SCB is sensitive to the voltage level of the energy stored capacitor bank.
Some SCBs compensate this kind of operation time variation by measuring the control voltage and further evaluating the operating time. A special module is designed for the charging of the energy stored capacitor bank. It not only converts the AC voltage to DC voltage, but also maintains the output DC voltage to a constant value without varying with any outside conditions. Thus the operation times are kept stable as well. By this method, the influence of control voltage on the operation time is eliminated.

(2) Influence of the ambient temperature

It was reported that the operation times of some pneumatically/hydraulically operated circuit breakers of transmission level are obviously affected by the ambient air temperature. However in medium voltage level, especially for the permanent magnetic actuators, investigations on temperature dependency of the operation times are still limited. Experimental study has been carried out on the influence of ambient temperature on the operation times of the developed SCB.

An SCB together with the developed SCU were enclosed into a temperature adjusting device, only some wires were stretched out through a thermally isolated hole for the purpose of control and measurement. A 12 kV VCB with its 3 poles each driven by an individual permanent magnetic actuator, which is similar with the developed SCB but more compact was used in the experiment, due to the dimension limitation of the temperature adjusting device.

The opening and closing times at different temperatures were measured. The experimental result shows that the variations of the operation times are less than 1ms, with the ambient temperature varying from -50 °C to 70 °C.

The principles and the configuration of the developed SCB are identical to that of the experimental model, except the size, so it can be concluded that the influence of the ambient temperature on the operation time of the developed SCB can be neglected.

(3) Influence of other long term factors

The long term factors here refer to the factors that may lead to drifting of the operation time gradually over a long term, such as those associated with ageing, mechanical wear and electrical erosion, etc. The so called adaptive control method is applied to compensate for these kinds of operation time drifting, as shown in the following equation.

\[ T_2 = T_1 + \alpha(T_m - T_1) \]  (2)

Where \( T_2 \) is the predicting operating time of next time, \( T_1 \) is the last operating time, \( T_m \) is the last measured operating time, \( \alpha \) is the weighing factor, to ensure that the statistical and periodic changes are not amplified, \( \alpha \) is limited to less than 1.

4. TYPE TESTS FOR THE SCB

(1) EMC Tests

High voltage switchgears require high reliabilities; unfortunately very severe electromagnetic disturbances usually exist in their working environment. Therefore the electromagnetic compatibility becomes one of the most important properties of the SCB. Generally, the system is interfered by the electromagnetic noises through 3 ways, radiated interference, coupling interferences from the I/O paths and the coupling interferences from the power source. The radiated interference is avoided effectively by perfect design of the electromagnetic screen and proper earthed of the system. All the I/O paths are isolated using the optoelectronic couplers. Hence the coupling interferences from the I/O paths are greatly minimized. The coupling interferences from the power source are suppressed by selecting of a high quality power source, in front of which a effective filter is inserted. On the other hand, software methods are also applied to enhance the EMC capability of the SCU, such as the use of the watchdog timer technology, the setting of the program traps technology and the redundant codes technology, etc. The SCB passed the EMC tests from the EMC laboratory of XIHARI, the national laboratory for high voltage apparatus tests.

(2) Mechanical Operation Test

Capacitor bank switching is a very frequent operation. This requires the circuit breaker to have a very long mechanical life cycle. One of the prominent features of the permanent magnetic actuator is its long mechanical operation cycles. To verify this, mechanical life cycle test of up to 100,000 operations has been performed on the developed SCB.
Controlled switching for capacitor bank tests have been performed to verify the practical effects of the SCB. The tests consist of 168 times of O-C operation. The tests result passed the C2 category of the capacitor bank opening, which implies it has “very low expected re-strike probability”. Figure 5 shows a typical oscillogram of the test waveforms, which shows the making at voltage zero. No signs of obvious inrush currents can be observed from the oscillograms of the test. To make a comparison, the capacitor bank switching test was repeated with the controlled switching function disabled. This time, the test result passed only C1, category of the capacitor bank opening, which means it has “low expected re-strike probability”, due to more re-strikes than that in the controlled switching case during the opening operations.

5. CONCLUSION

An MV SCB has been developed by embedding an SCU system which is configured on the basis of the PIC16F877 to a 40.5kV VCB driven by permanent magnetic actuators. Capacitor bank switching tests have been performed on the developed SCB. It is shown from the test results that the inrush currents during the energization and the re-strike probabilities during the deenergization of the capacitor banks can be greatly minimized by the application of the developed SCB.

6. REFERENCES

[1]. IEC62271-100