HIGH-SPEED AC CIRCUIT BREAKER AND HIGH-SPEED OCR

Young-woo JEONG
LSIS – S.Korea
ywjeong@lsis.biz

Hyun-wook LEE
LSIS – S.Korea
hwleea@lsis.biz

Seok-won LEE
LSIS – S.Korea
seakwonl@lsis.biz

Young-geun KIM
LSIS – S.Korea
youngk@lsis.biz

ABSTRACT

In electrical power systems, especially highly networked and become smart grid recently, faster protection relay and faster circuit breaker are more desirable for system stability at short circuit accidents. Nowadays general interruption time of circuit breaker is 3~5 cycle and trip signal sending time of a protection relay is about 2 cycle for instant operation. Most cases these circuit breaker and protection relay are sufficient for protection of the power systems but some special cases faster circuit breaker and relay are required. We proposed a prototype AC high speed circuit breaker which could interrupt the short circuit current of 12.5kA, 25.8kV within 1 cycle of 60Hz. Also we developed a prototype over current relay(OCR) which can send a trip signal within 1/2 cycle of 60Hz. We carried out a short circuit test these high speed circuit breaker and OCR in combination. At making current of maximum DC components defined in IEC 62271 100 32.5kA peak, 25.8kV, current was sensed and interrupted within 1 cycle.

INTRODUCTION

Since the electric power system has been used in our life several kinds of circuit breaker and protection relay have been developed and used. Some are using now and others are not used anymore. While interrupting the short circuit the arc always happens and in AC system arc is extinguished at current zero if there is sufficient dielectric strength between electrodes of a circuit breaker. To extinguishing arc, oil, air, magnetic field, SF6 gas and vacuum are used. Nowadays in MV circuit breaker, vacuum is most desirable extinguishing method and above HV SF6 gas is strongest method for high dielectric strength and good arc extinguishing characteristics. Another principal part of circuit breaker is a mechanism which separate electrode to interrupt currents. Also there are several kinds of circuit breaker mechanism. Nowadays spring, pneumatic, hydraulic, electromagnetic methods are widely used. Upto date circuit breaker which uses these methods interrupt currents in 3 or 5 cycles after receiving the trip signal from the protection relay. These interruption time is shortened quietly comparing the past. But we thought there are more possibilities to shorten the interruption time if we use new method or combinate the present technologies. So we proposed a high speed AC circuit breaker which is consisted of MV vacuum interrupter and hybrid mechanisms. Now vacuum interrupter is most compact and effective arc quenching method in MV level so we choose the VI for our prototype circuit breaker. We did not amend the VI which we adopted. We focused to mechanism for our high speed circuit breaker. The first type high speed mechanism is a hybrid mechanism which is consist of permanent magnet actuator(PMA) and Thomson coil actuator. This mechanism compensate the demerits of each other. Thomson coil actuator is one of the most fast mechanism used in circuit breaker. But this actuator can not be controlled in position precisely. And PMA can be controlled in position but is quite slow compare to Thomson coil actuator. We adopted the merits of each mechanism and eliminated the demerits of each mechanism. The mechanism opens with Thomson coil and PMA and closes with only PMA. Because there is no need to quick closing. The second type high speed mechanism is a conventional spring mechanism with fast reacting solenoid device which is consist of a conventional solenoid and miniature Thomson coil actuator. This type shorten the delay time of the latch removing process. This method can be a economic high speed mechanism solution. Fast fault detecting is also essential point for high speed elimination of short circuit accident. Difficult parts to shorten the OCR tripping time are fault decision algorithm and delay time of the internal mechanical relay. So we proposed a new hybrid fault decision algorithm and adopted a solid state relay. Nowadays almost digital protection relays use Discrete Fourier Transform(DFT) to fault decision. After 1 cycle of power frequency DFT discriminate the magnitude of only the power frequency components from the current signal and this make the OCR decide the fault correctly without error. This makes it possible to eliminate the dc component and surge from the current signal. So the OCR intrinsically has a tripping time of about 2 cycle. Sometimes this trip output time can be large for special cases and large fault current. The hybrid algorithm which we proposed is using three decision factor of DFT, the magnitude of instant signal and the magnitude of derivative of the signal. At very high current signal, the proposed OCR uses the magnitude and derivative of the current otherwise rather small current uses the DFT information. So when the critical accident is occurred in power system, the new OCR can make a trip signal within 1/2 power frequency cycle and in over current region 1~1.5 cycle. We made a short circuit making and interruption test with the high speed circuit breaker and OCR which we proposed in high power laboratory.

High speed circuit breaker

We targeted a 24kV class high speed vacuum circuit breaker for distribution. The specification of the prototype which we made is 25.8kV, 600A, 12.5kA, 60kV AC, 125kV BIL.

A. Thomson coil actuator with PMA high speed CB

The structure of the first prototype is almost same as conventional VCB with PMA driving except addition of Thomson coil actuator. Fig. 1 shows the concept of it.

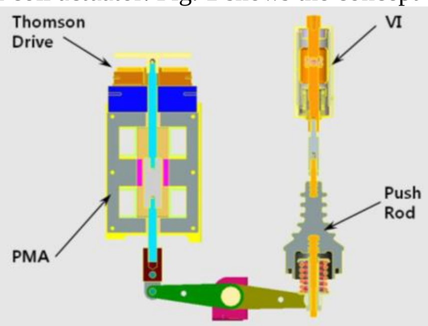

Fig. 1: Concept of the high speed CB with Thomson coil actuator and PMA

A peculiar point of this circuit breaker is that we use both side of the PMA moving rod. One side close the VI by only PMA and the other side open the VI by Thomson coil actuator and PMA. Both closing and opening operation is kept by the holding force of the PMA magnet. The Thomson coil actuator was derived by capacitors and SCR switch. So the high speed circuit breaker needs two kinds of driver circuit which actuate PMA and Thomson coil. This is rather expensive solution but we can get a 1 cycle interruption of largest current duty eg. T100a.

B. Thomson coil actuator with spring mech. CB

The concept of the second prototype is a conventional spring VCB with very high speed trip device which has no delay time. This high speed trip device is consist of a conventional solenoid coil and Thomson coil actuator. This is also hybrid type. A conventional VCB with spring mechanism has a trip device delay time upto 15 ms. We reduced a delay time of it upto 1~1.5 ms.

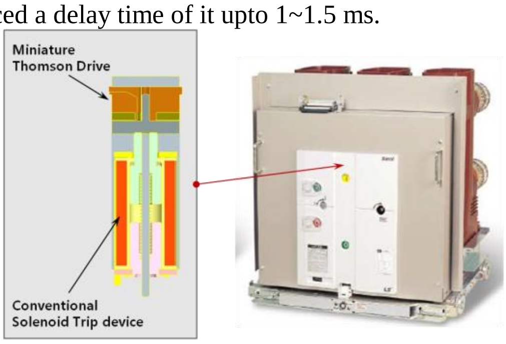

Fig. 2: Concept of the high speed CB with Thomson coil actuator and conventional spring mechanism

This type is more simple, slim and cost effective.It require additional device of one small Thomson coil actuator of which diameter is 26mm and one driving circuit of small energy. We get a 1.5 cycle interruption for T100a duty.

High speed over current relay

OCR is the basic protection relay for power system and also essential, important. Conventional digital OCR uses DFT algorithm to decide the fault status because this algorithm eliminate the unnecessary mis trip due to noise and surge. The power frequency component after the processing inform us the correct status. But this operation needs the time of 1 cycle and OCR require further electronic processing time, so usually send the trip signal after 2 cycle. Sometimes this can be late and the power system is more stable if we interrupt short circuit as fast as possible.

We devised a hybrid algorithm for high speed OCR. For very large current signal, OCR use the signal of the current and derivative of it with some noise filtering. And for rather small accident current signal(usually less than twice of the setting level of instant operation and this can be selected by a operator), the OCR uses DFT algorithm like conventional OCR. We investigated the discrimination capability of our algorithm by EMTP simulation for many cases.

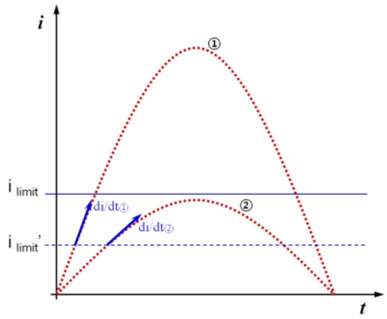

Fig. 3: Algorithm illustration of instant current and derivatives of it

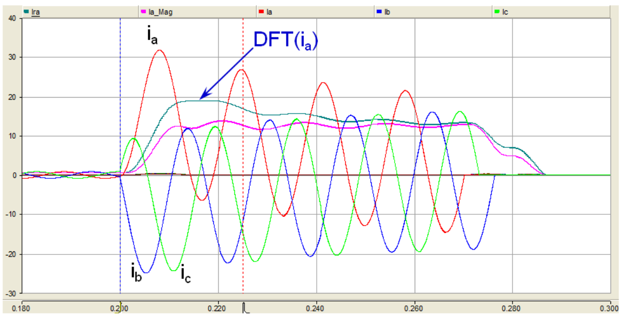

Fig. 4: 3 phase short circuit and DFT signal of it from EMTP simulation which we use for investigation of the algorithm

From the above graph, we can know if we use the derivative information of the instant current signal, it is trip condition or not at earlier i limit' level before i limit value. For our algorithm we utilizes current, derivatives of it and DFT with some filtering and holding process.

We made a digital OCR with above algorithm and it send a trip output signal range of 3.4~7.9[ms], eg. under 1/2 cycle of 60Hz, after occurrence of a fault. There was no mistrip during our short circuit tests.

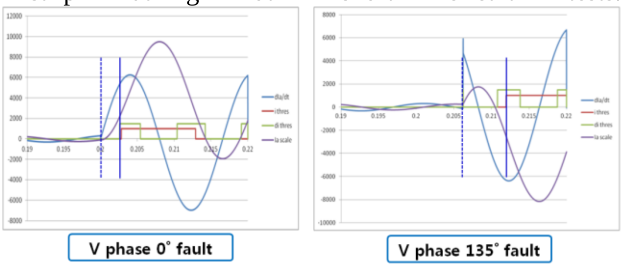

Fig. 5: Trip output time simulation for the fault occurrence of every phase angle and shortest and longest case

COMPONENT AND SYSTEM TEST RESULTS

A. No load characteristics of the CB

From the measurement about no load stroke curve we could acquire some intuitive. The mechanism with Thomson coil actuator and PMA was faster than spring mechanism with miniature Thomson coil actuator applied solenoid trip device for both delay time and speed. But Thomson coil actuator with PMA was not so good for linearity of the stroke curve and rebounce characteristic. Never the less there were no degradation of interruption capability due to linearity of the stroke curve and opening speed was a strongest factor for interruption of a short circuit current.

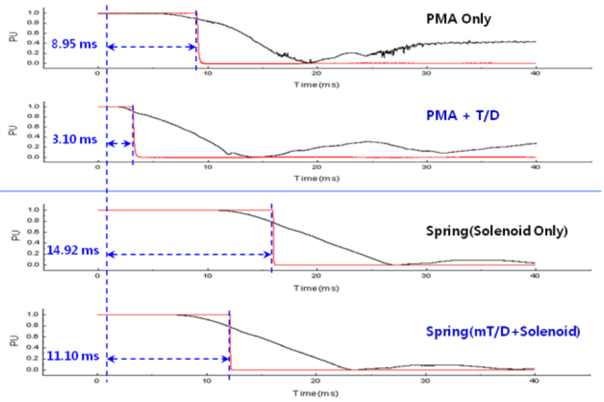

Fig. 6: No load characteristic stroke curve of the 2 kinds of high speed mechanism(number in [ms] means time between trip signal and point of contact opening)

The opening speed and rebounce magnitude was 2.15 [m/s], 15% for PMA type and general spring mech. value for spring type.

B. EMI/EMC and Environmental test for the OCR

We developed a fully digital high speed OCR. The OCR is consisted of main CPU board, A/D conversion board, HMI board, SMPS/DI/DO board, LCD board and case. The OCR calculate all the information and operate process in digital so we adopted newest CPU of 120 MHz clock speed with floating point calculation capable. And for fast trip signal output, we adopted a solid state relay(IGBT). The OCR has many functions of recent digital protection relays like recording the accident current signal, power fail protection, real time clock, event recording, watch dog etc. For verification of reliability of the OCR, we carried out functional tests, EMI/EMC tests and environmental test and we acquired a success report finally. The trip time was below 1/2 cycle and there were no mistrip for unsatisfying conditions. We carried out the residual tests by the IEC 60255 and plus more severe tests according to the internal standard for quality assurance of our company.

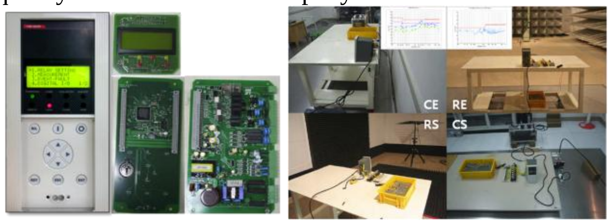

Fig. 7: The appearance of the high speed OCR and photograph of the EMI/EMC tests

C. System test result of the CB and OCR

We verified the detection and interruption capability for the fault current. To apply most severe condition, we applied a 24kV 12.5kA T100a condition. The DC factor was 2.6 times of the short circuit current. We only made a short circuit current and detection and interruption was made by the OCR.

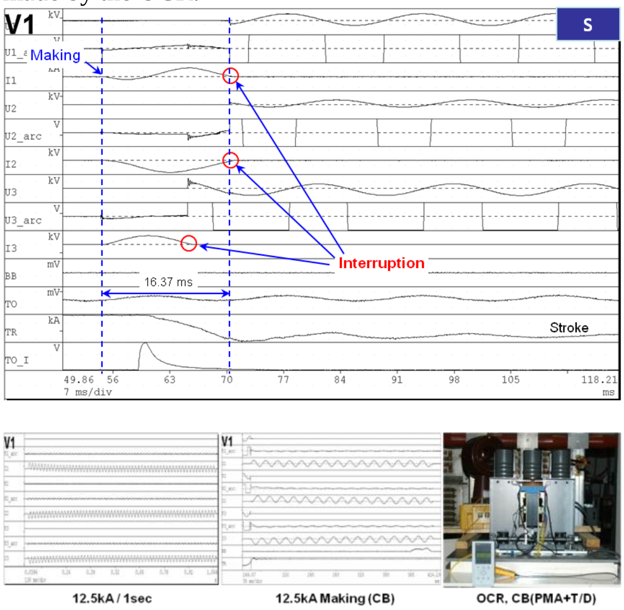

Fig. 8: Oscillogram of high power tests and photograph of the system(PMA+Thomson coil actuator type CB)

Short circuit test was conducted in the high power laboratory of our company LS industrial systems, its name is PT&T, which has short circuit generator of 1,000MVA. We carried out a direct test. For the first combination of high speed OCR and high speed VCB with Thomson coil actuator and PMA, the total interruption time was 16.37 [ms] from the occurrence of a short current to interruption of all 3 phases. We also carried out a short circuit endurance test for 1 second and short circuit making test. For short circuit interruption test, making was made by a making switch of the high power laboratory.

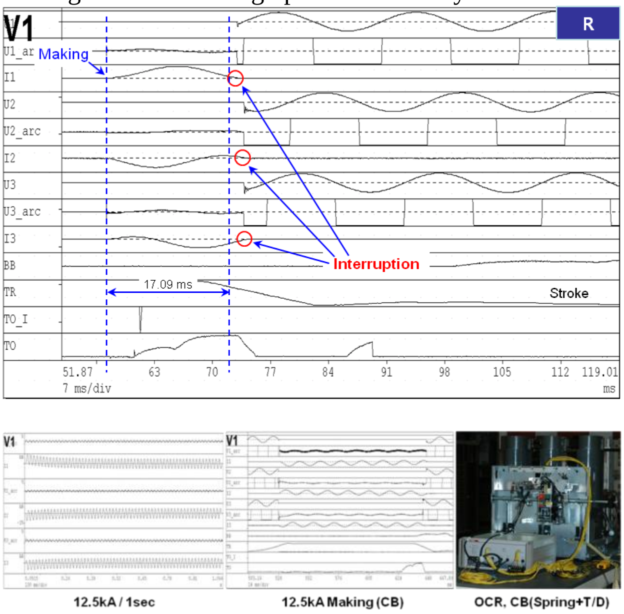

Fig. 9: Oscillogram of high power tests and photograph of the system (Spring+Thomson coil actuator solenoid type CB)

For the second combination of high speed OCR and high speed VCB with Thomson coil actuator applied solenoid trip device and conventional spring mechanism, the total interruption time was 17~29 [ms] from the occurrence of a short current to interruption of all 3 phases. We also carried out a short circuit endurance test for 1 second and short circuit making test. For short circuit interruption test, making was made by a making switch of the high power laboratory.

CONCLUSION

*** High Speed Mechanism**

We devised 2 types of high speed mechanism for MV class vacuum circuit breaker. We actually made prototypes and carried out several high power tests and the results were very good.

1) A hybrid mech. of PMA and Thomson coil actuator
- Shows very small delay time range of 1 [ms]
- High speed for VCB mech. range of 2.15 [m/s]
- Good result for interruption(T100a for 24kV 12.5kA), making,mechanical endurance
- “1 cycle Circuit Breaker” enableAll images should be included in the body of the document, positioned as close as possible of the text mentioning them. Images may be one or two columns wide.

2) A hybrid mech. of Spring and Thomson coil actuator applied solenoid trip device
- Shorten the delay time of the conventional solenoid trip device with small additive equipment
- Good result for interruption(T100a for 24kV 12.5kA), making,mechanical endurance
- Economic solution
- “1.5 cycle Circuit Breaker” enable

*** High Speed OCR**

We proposed a new hybrid algorithm which use DFT, instant current and the derivative of it. By using these we could eliminated the unintentional trip at low fault current and acquire high speed trip at large fault current.
- OCR trip time less than 1/2 cycle
- mistrip, EMI/EMC, environmental tests(IEC): success

*** High Speed protection system**

The high speed OCR and VCB showed good results for s ystem tests. We verified that the maximum fault current c an be interrupted within 1 cycle with our high speed OCR and VCB in MV circuit.

*** Application**

These outputs can be adopted to High Speed Transfer Swi tch and DC High Speed Circuit Breaker. Also several co mponents of these system can be applicable to many elect rical machinery, especially switches.

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