The Application and Benefits of Multi-phase Auto-reclosing

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Abstract - In this paper we explain the disadvantages in using single- and three-phase auto-reclosing on double circuit overhead transmission lines.
Multi-phase auto-reclosing, which has been applied since the early 1960's in Japan can overcome these disadvantages. We describe the method of multi-phase auto-reclosing and the benefits that can be achieved in transient system stability and our experience in the application of multi-phase auto-reclosing in Japan.

Keywords: double circuit transmission lines, discrimination of fault phase, high-speed auto-reclosing, multi-phase auto-reclosing, single-phase auto-reclosing, three phase auto-reclosing

1. Introduction

Auto-reclosing is an important technique for the speedy restoration of faults, improvement of system stability and the prevention of power system disturbances.

In Japan overhead transmission lines for EHV networks generally consist of double circuit lines because of the limited size of land areas.

For the purpose of improving transient stability, multi-phase auto-reclosing has been applied to double-circuit lines in Japan since the 1960's.

Single- and three-phase auto-reclosing, being globally applied had been in use before multi-phase auto-reclosing was adopted. These methods present problems in terms of transient stability because auto-reclosing can be unsuccessful for multi-phase and double circuit faults when these methods are applied.

We believe that multi-phase auto-reclosing will play an increasingly important role in power networks around the world as one of the key tools and techniques available to utilities in assisting them in improving power system stability and security. In this paper we have discussed the impact of multi-phase auto-reclosing and the problems that need to be solved.

Firstly, for the successful application of multi-phase auto-reclosing, the ability to discriminate the faulted phase and the system interconnection is necessary. A PCM current differential protection relay is appropriate for these purposes. This kind of relay can easily recognize the system interconnection by using communication circuits, through which the relays on both terminals can transmit the state of circuit breakers to one another.

Secondly, a short dead time is effective for system stability. But for higher voltages a longer duration is needed to recover the interpole insulation on circuit breakers. To solve this problem many methods which extinguish the secondary arc voltage in a short a time as possible for transmission lines have been proposed. We briefly introduce the results of a study in Japan and finally we report a number of examples of lightning faults on EHV networks and the effect of multi-phase auto-reclosing. This technique has been applied to EHV networks in Japan since 1960.

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2. Conventional auto-reclosing method

For the purpose of improving transient stability, auto-reclosing is applied. Globally single- and three-phase auto-reclosing are applied to overhead double circuit transmission lines.

2.1 Single-phase auto-reclosing

In single-phase auto-reclosing only the faulted phase is tripped for earth faults and the voltage phase angle difference between both terminals can be small enough to continue the supply of power during tripping of the faulted phase.

This method can be applied to both single and double circuit overhead transmission lines.

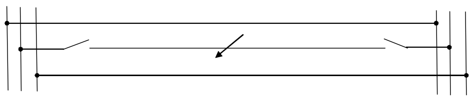


Figure 2.1 Single-phase auto-reclosing

2.2 Three-phase auto-reclosing

In three-phase auto-reclosing a faulted line trips as per a multi-phase fault and auto-reclosing is performed on the condition that there is a system interconnection between the two terminals of the healthy line.

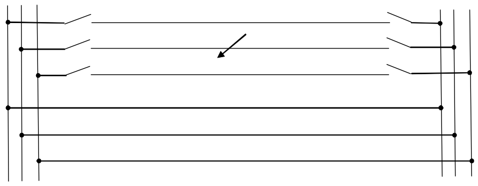


Figure2.2 Three-phase auto-reclosing

2.3 Disadvantage of single- and three-phase auto-reclosing

Single- and three-phase auto-reclosing have the following disadvantages and cause a deterioration in the transient stability.

-Single-phase auto-reclosing is unsuccessful for a multi-phase fault.

-Three-phase auto-reclosing is unsuccessful for a double-circuit fault.

3. Multi-phase auto-reclosing

As an alternative multi-phase auto-reclosing can be applied and provide a solution to the problems described when using single- and three-phase auto-reclosing for the case explained in section 2.

3.1 Method of multi-phase auto-reclosing

On Multi-phase auto-reclosing, if at least two different phases remain in a power transmission state, all the phases tripped can be reclosed. This idea is based on the fact that one transmission line has six phases for a double-circuit line. Multi-phase auto-reclosing method includes both single and three-phase auto-reclosing. For example if a three-phase fault occurs on one of the lines of a double-circuit line configuration and a single-phase fault occurs on the other, auto-reclosing is performed. Table I presents details of the faulted phases for faults on double circuit lines installed on the same towers.

Table I Details of faulted phases of double circuit lines on the same tower

No	Fault phase						Tripping and reclosing	
	#1 line			#2 line			#1 line	#2 line
	A	B	C	A	B	C		
1	×			—	—	—	1φT→R	
2	×	×		—	—	—	3φFT	
3	×	×	×	—	—	—	3φFT	
4	×						1φT→R	
5	×			×			1φT→R	1φT→R
6	×	×					2φT→R	
7	×				×		1φT→R	1φT→R
8	×	×		×			2φT→R	1φT→R
9	×	×		×	×		3φFT	3φFT
10	×	×	×				3φT→R	
11	×	×				×	2φT→R	1φT→R
12	×	×			×	×	2φT→R	2φT→R
13	×	×	×	×			3φT→R	1φT→R
14	×	×	×	×	×		3φFT	3φFT
15	×	×	×	×	×	×	3φFT	3φFT

×:Fault
—:The line is out of service
1φT→R: single-phase tripping and reclosing
2φT→R: two-phase tripping and reclosing
3φT→R: three-phase tripping and reclosing
3φFT : three-phase final tripping

If multi-phase auto-reclosing is applied, auto-reclosing is possible for the cases indicated by the shaded region on table I.

3.2 Effect of multi-phase auto-reclosing

When using single- and three-phase auto-reclosing on double-circuit lines, if a multi-phase fault occurs on the line or a same phase single-phase fault occurs on the double-circuit line, the effect on transient stability is small. But if a multiple fault occurs on a double-circuit line, power transmission on the double-circuit line will be lost. A loss of such a transmission route can cause major power supply interruption with consequent disruption to load or expose the network to potential system stability problems.

Alternatively, when using multi-phase auto-reclosing on double-circuit lines, if the above fault occurred, the phase angle difference will be small enough to permit the continuation of the supply of power during tripping the faulted phase.

Figure 3.2.1 shows the relationship between the effective power and the voltage phase angle from the occurrence of the fault to the reclosing of the circuit breaker.

On the phase angle curve, power transits from point A of Pu, on which the synchronous generator normally operates in the double circuit line, to point G in the case of a three phase to earth fault.

There is a transit from Point H to point C, when the fault is removed of angular difference θ_2 and the effect of the deceleration energy is to reduce the angle. The angle transits from θ_5 on which auto-reclosing operates to θ_6 until the acceleration energy (S_3) is equal to the deceleration energy. Because the output of the generator is above Pu, the angular difference is forced to reduce. Finally the energy is restored to the stable operation angle (θ_0).

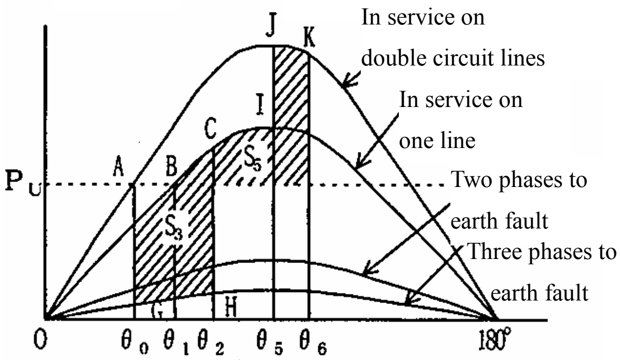
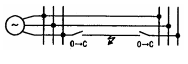
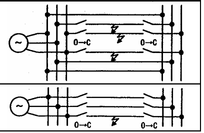
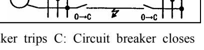


Figure 3.2.1 Relation to the angular difference on double circuit lines

Table II shows a summary of the auto-reclosing.

Table II Methods of auto-reclosing

Method	Outline	Schematic diagram
Single-phase autoreclosing	On EHV overhead single circuit transmission line the only fault phase trips in single-phase to ground fault and the phase reclosing after dead time.	
Multi-phase autoreclosinh	On EHV overhead double circuit transmission lines the only fault phases trip in multi-phase fault.	
Three-phase autoreclosing	A fault line trips in fault and recloses after a certain period of time.	

O: Circuit breaker trips C: Circuit breaker closes

4. Technical problem

In order to apply multi-phase auto-reclosing, it is necessary to confirm with certainty the system interconnection between both terminals and discriminate the fault phase(s).

The higher the voltage level, the longer the time required to recover the interpole insulation on circuit breakers. To solve this problem many methods which extinguish the secondary arc voltage in a reduced time have been proposed.

4.1 Faulted phase discrimination and system interconnection

For application to multi-phase auto-reclosing, the ability to discriminate the faulted phase and the system interconnection for at least two phases is required. The PCM current differential protection relay has solved the above problem. The current data for each phase in the transmission line terminals is sent between terminals and the relay performs differential protection using the current data. Therefore the relay can discriminate the faulted phase.

The status of each phase of the circuit breaker is transmitted and the relay is able to recognize the system interconnection.

1) Configuration of PCM current differential relay

Figure 4.1.1 shows an example of the construction of the PCM current differential relays used in Japan. The current for each phase of the transmission line terminal is sampled 12 times per cycle at rated power frequency by the data acquisition unit DAU.

Sampling is performed simultaneously for both terminals, and the currents are converted into 12-bit digital data. The current data is converted into serial data and transmitted to the other terminals.

The serial data received from the remote terminal is converted to parallel and is acquired by the differential discriminator DD, which uses a microprocessor. The DD performs differential protection using the acquired data.

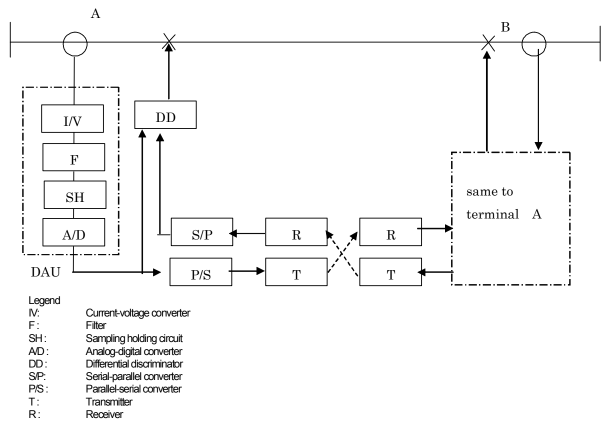


Figure 4.1.1 PCM current differential relay system

2) Block diagram for checking system interconnection

Figure 4.1.3 shows the block diagram for checking the system interconnection. The relay at terminal A acquires the status of each phase of the CB and DS at terminal B via the communication circuit.

The system interconnection is checked using the CB and DS status at terminal A and B.

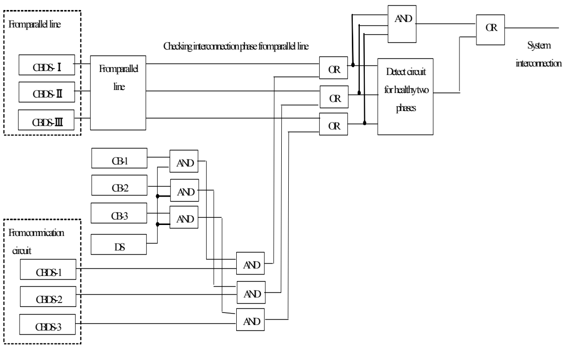


Figure 4.1.3 Interconnection check for multi-phase auto-reclose

4.2 Secondary arc extinguishing in UHV systems

We expect that the system interconnection will consist of UHV systems in the near future. Multi-phase auto-reclosing is necessary in order to avoid double-circuit outages and to ensure transient stability. Secondary arc extinguishing time in UHV transmission lines is longer than in EHV transmission lines because of the electrostatic induction from the parallel line and healthy phases after tripping the faulted phases.

Dependent upon environmental factors the arc cannot often be extinguished within an ordinary dead time.

Therefore it is an important technique to shorten the time for arc extinguishing.

The relationship between the dielectric strength and the recovery time depends upon the voltage level, the length of the transmission line and the weather conditions. Figure 4.2 shows the relationship between the dielectric strength and the recovery time at 500kV and 1000kV. It has been approximately 1 second at 500kV, and more than 4 seconds at 1000kV.

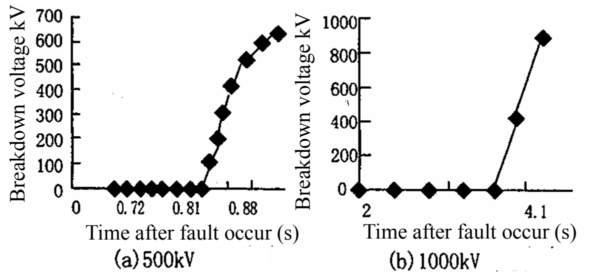


Figure 4.2 Relation between dielectric strength and recovery time

1) Method of extinguishing the secondary arc current - High speed grounding switch

The following methods can be used to extinguish the secondary arc current:

- The secondary arc current caused by static coupling is extinguished using a zero-phase sequence compensating reactor.
- To physically ground the faulted phases to extinguish the secondary arc current, namely high speed grounding switch (HSGS).

The time required to extinguish the arc depends on the lightning outage performance in the case of the former method. Especially, the time is longer in case of faults on double circuit lines.

Otherwise the time is stable for any lightning outage performance. Figure 4.2.1 shows the HSGS method. After the faulted phases have opened, grounding the faulted phases by closing the HSGS extinguishes the secondary arc and then the HSGS are opened.

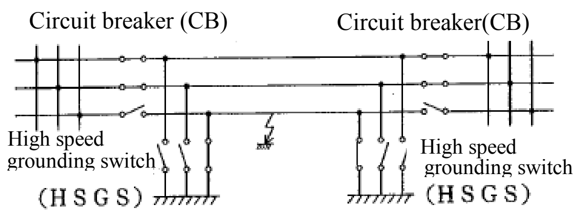


Figure 4.2.1 High speed grounding switching method

2) Improvement in reliability

The HSGS method requires both speed and reliability to execute the following sequence:

① Fault occurs
② Opening CB on the faulted phases
③ Closing HSGS on the faulted phases
④ (Extinguishing the second arc)
⑤ Opening HSGS on the faulted phases

⑥ Closing CB on the faulted phases (auto-reclosing)

Closing the HSGS before opening the CB or closing the CB during the closure of the HSGS can lead to the failure of the HSGS method.
For this reason the HSGS must check for opening of the CB for the fault and closing the HSGS. The following are practical examples.

1) Checking CB opening for the faulted phases
The condition of CB opening in the faulted phase is the following electrical and mechanical condition:

- The electrical condition is that the protection differential output signal from the current differential relay cleared following its operation for the fault
- The mechanical condition is that the CB is open at both terminals.

If these conditions are satisfied, the command for closing the HSGS is output.

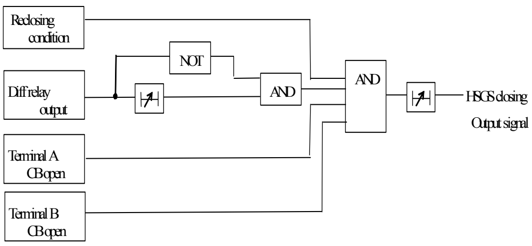


Figure 4.2.3 Condition of closing HSGS

2) Checking closing HSGS
The condition for reclosing the CB is that the HSGS at both terminals are closed and the condition for auto-reclosing are satisfied. Figure 4.2.3 shows a block scheme for opening the HSGS at both terminals.

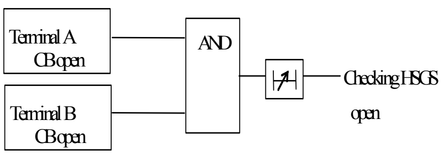


Figure 4.2.3 HSGS open check

The status of the HSGS is acquired via the communication circuit.

3) Field test result of HSGS
In Japan a field test for HSGS has been conducted over three years. Figure 4.2.4 shows the field test result for a 275kV transmission line applied to the HSGS method.
The measured data provided the following result:

1) Effective value of induced voltage from the healthy lines is from about 15 to 20kV.
2) Effective value of HSGS current is about 5.5A.
3) It takes 30ms to extinguish the secondary arc. The period measured is taken from tripping of the faulted phase to the appearance of the induced voltage.

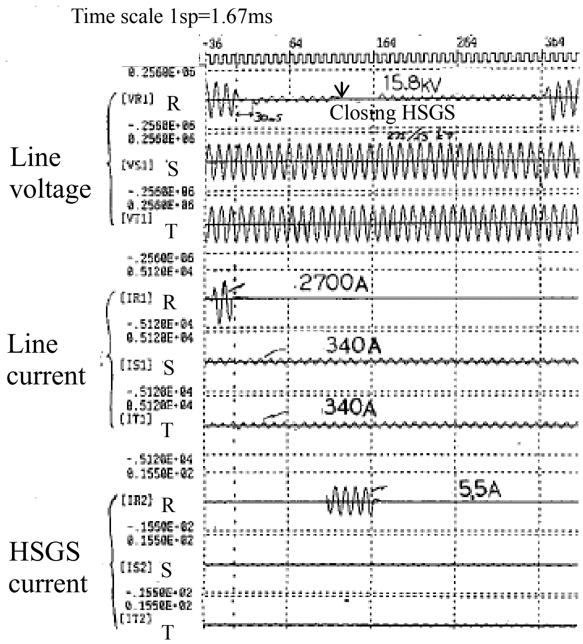


Figure 4.2.4 Field test result of HSGS

This result shows that the coordination of system protection is vital. As the secondary arc is spontaneously extinguished before closing the HSGS in this case as applied at the 275kV level, it does not show that the HSGS method is effective for extinguishing the arc. But the induced voltage disappears while closing the HSGS. Therefore the method would be able to extinguish secondary arc.

Recently the method has been applied to 765kV transmission lines in Korea.

5 Actual data of multi-phase auto-reclosing in Japan

In Japan multi-phase auto-reclosing has been applied since the 1960's in EHV transmission lines where there is no problem with respect to generator shaft torque in large capacity power stations. Table III shows details of the faulted phases for faults on double circuit lines installed on the same towers at HV and

EHV levels.

For double circuit faults; the rate of double circuit faults in which multi-phase auto-reclosing performs auto-reclosing for both double circuit lines, increases by about 30% in comparison to single- and three-phase auto-reclosing methods. This contributes to transient stability.

Table III Details of faulted phases for faults on double circuit lines at HV and EHV voltage levels

(1980～1985)

Number of faulty phase				Lighting Faults		Classification
Per Double circuit	Per Circuit		Reference Diagram	Number of Faults	Rate(%)	
	Line 1	Line 2				
1	1	0		481	72.8	S
2	2	0		58	8.8	
3	3	0		19	2.9	
1	1	1		35	5.3	D1
2	1	1		8	1.2	
	2	1		21	3.2	D2
3	2	1		1	0.2	
	3	1		8	1.2	
	2	2				D3
2	2	2		14	2.1	D4
3	3	3		7	1.1	
	3	3		9	1.4	
Total				661	100.0	

Legend

S: Single circuit faults

D1: Single phase auto-reclosing performs high-speed auto-reclosing for double circuit lines.

D2: Single phase auto-reclosing perform high-speed auto-reclosing for one of double circuit lines. Multi-phase auto-reclosing performs one for double circuit lines.

D3: Single-phase auto-reclosing cannot perform high-speed auto-reclosing. Multi-phase auto-reclosing performs high-speed auto-reclosing for double circuit lines.

D4: Impossible with any auto-reclosing scheme.

6. Conclusion

In this paper we have shown that multi-phase auto-reclosing method is available for double circuit transmission lines. We introduce the HSGS method which is effective in speedily extinguishing secondary arc at the 765kV level and above and is viewed as key to the success of multi-phase auto-reclosing.

Multi-phase auto-reclosing can make a major contribution system stability.

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