THE APPLICATION OF HIGH SPEED GROUNDING SWITCHES ON EHV/UHV POWER SYSTEMS TO ENHANCE SINGLE POLE RECLOSING - CONTROL AND PROTECTION

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Introduction

The benefits of single pole relaying are identified on the basis of:

A. Improvements in transient and steady state stability.

B. Reduction of switching overvoltages.

C. Reduction of shaft torsional oscillation of large thermal units.

D. Remote generating stations connected to load centers with one or two transmission lines are probably the classical example where the application of single pole relaying can significantly improve availability and system reliability.

To consider single pole relaying and its additional benefits, it is necessary to document relative probabilities of the type of faults on a transmission line. The traditional statistics are shown on Table 1.

TABLE 1
Relative Number of Different Types of Faults on HV Lines

Fault Types	Percent
Single Line-to-Ground Faults	70
Phase-to-Phase Faults	15
Double Line-to-Ground Faults	10
Three Phase Faults	5
Total	100

On 525 kV EHV lines the conductor spacing is increased; therefore, the percent of multiphase type of faults decreases. The statistics for the relative number of different type of faults on the BPA 525 kV EHV system are shown on Table 2.

TABLE 2
Relative Number of Different Types of Faults on the BPA 525 kV EHV System

Fault Types	Percent
Single Line-to-Ground Faults	93
Phase-to-Phase Faults	4
Double Line-to-Ground Faults	2
Three Phase Faults	1
Total	100

Table 1 and 2 clearly demonstrates that EHV lines and future UHV lines benefit the most from single pole relaying techniques.

BPA's present policy is to install single pole relaying on all future 525 kV lines and retrofit many of the existing 525 kV lines to single pole trip. There are many papers published hitherto on the subject of Single Pole Relaying and various schemes are available; therefore, this paper will not discuss the ways and means one can provide Single Pole Relaying protection.

By '84

Brief Description of the Specific Problem.

Successful Single Pole Relaying provides high speed tripping of the faulted phase at both end terminals. The trip in turn is followed by a single shot reclose initiation of the open phase usually after 0.5 to 1 second time delay. A time delay of 0.5 to 1 second is needed to ensure that the primary arc of the transitory fault is extinguished. After clearing the primary arc, a secondary arc may continue if the line loading, the capacitive and inductive coupling of the two unfaulted phases are of sufficient quantity. This can in turn prevent successful reclosing of the opened phase. More detailed discussion of the theory of secondary arc and its causes can be found in existing literature. [1, 2, 3]

Methods of Secondary Arc Reduction.

There are basically five methods for reducing the Secondary Arc Current and recovery voltage. These methods are listed and discussed briefly below:

A. Permanently connected banks of four reactors. The scheme was first proposed by Knudsen [4] and again by Kimbark [5]. This scheme has been successfully applied worldwide and familiar to most engineers.

Advantages: Proven design.

Disadvantages: The high cost of four reactors. Operational problems associated with system voltage control when the line is heavily loaded. From a system operation viewpoint the shunt reactors may be required at places other than the subject terminal(s) to meet voltage control requirements, thus the possibility of costly duplication of hardware. The estimated cost of a four reactor scheme is $2,250,000 per terminal.

B. Modified selectively switched four reactor scheme. This scheme is proposed by R. E. Dietrich and J. Esztergalyos at terminals where shunt reactors are already available or planned for system voltage control. [6] The scheme basically calls for a shunt reactor switch which can be closed at high speed when the single pole trip scheme operates.

Advantages: The reactors are switched on line only when the system voltage must be regulated or when single pole switching is required. Basically, it is a more flexible approach than the one described in item A.

Disadvantages: The high cost of four reactors plus the cost of a high speed shunt reactor switch, plus the cost of the additional control scheme. Note that additional shunt reactors may still be needed at other terminals to meet system voltage control requirements thus again the possibility of costly duplication of hardware. The estimated cost of a modified four reactor scheme is $2,400,000 per terminal.

C. Series Capacitor Scheme. This scheme was proposed by Peterson and Dravid [7] but has never been used on a power system. The main advantage of this design appears to be that it poses no restrictions on the placement and operation of shunt reactors needed for system voltage control. The disadvantage is the complexity of designing such a scheme for a breaker and a half or a ring bus configuration. The estimated cost would approximately be the same as a four reactor installation described in item A.

D. High Speed Ground Switching Scheme. This scheme has been suggested previously but never actually applied on EHV lines. The concept was proven in a successful field test carried out by BPA. Detailed discussion of the test and its results can be found in the referenced publication [8].

Advantages: Low cost. The estimated cost of the ground switch scheme is $400,000 per terminal. From system operation viewpoint, the ground switch provides high flexibility. Shunt reactors can be placed at any point of the system since they are not a part of the single pole tripping scheme.

Disadvantages: More complex Control and Protection scheme.

This paper will describe the Control and Protection of High Speed Grounding Switches which will be installed on BPA's 500 kV lines to insure the success of high speed single pole reclosing.

High Speed Grounding Switch (HSGS) Performance Requirements.

The hardware specification of the HSGS is described as follows:

Ground Switch: BBC Type ELK ES3

Rated Voltage	500 kV
Max. Operating Voltage	550 kV
BIL	1550 kV
Recovery Voltage	78 kV
Interrupting Current	600 Amperes
Close and Latch Current	64 KA
CT ratio	600/5

Additional performance requirements are described in more detail.

HSGS Absolute Closing Speed.

HSGS absolute closing speed was selected at five cycles. Figure 1 illustrates the necessity of careful close speed selection.

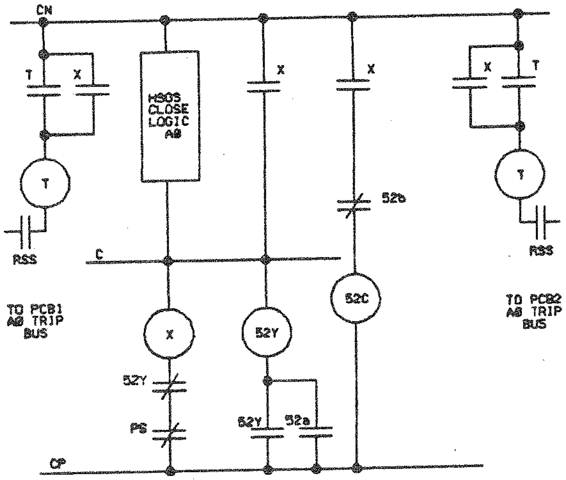

Figure 1. HSGS Simplified Close Bus Diagram.

Note that the line breakers PCB 1 and 2 trip bus is energized when the HSGS close bus is energized. Since the close speed was selected at five cycles and the adjacent PCB's trip speed is two cycles an absolute margin of three cycles will remain between PCB trip and HSGS close, thus minimizing the possibility of closing the HSGS when the adjacent breakers are still closed. The HSGS close speed can be more than five cycles for additional security but it is not recommended since it affects the total timing of the high speed single pole reclose operation.

HSGS Absolute Trip Speed.

The HSGS absolute trip speed should be between two to five cycles. The trip speed is not as critical but longer time delay is not recommended in order to retain the high speed single pole reclose operation.

HSGS Control and Protection Scheme.

The HSGS Control and Protection Scheme required the development of new relaying logic some of which are the "mirror image" of existing relaying concepts. The complete scheme is quite extensive, it includes logic as well as mechanical interlocks at every step of the close and trip cycle. The main features described as follows:

HV Line Single Pole Relaying Revision.

The line single pole relaying protection is a conventional direct underreach permissive overreach transfer trip scheme. The single pole relaying logic is used for faulted phase selection. An open-end echo back logic is added to monitor open phase condition at both end terminals. Figure 2 shows a simplified block diagram depicting the open end echo back logic.

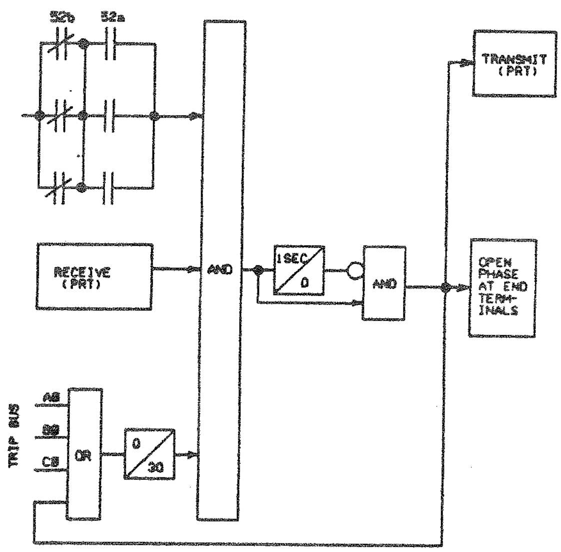

Figure 2. Open End Echo Back Logic.

The Signal to Close the ground switch is not initiated until the Open End Echo Back logic indicates open phase at both end terminals and the local breaker failure scheme is in the reset condition. A minor revision is required to monitor a breaker failure logic reset condition. Figure 3 is a simplified logic diagram depicting the basic HSGS Signal to Close logic.

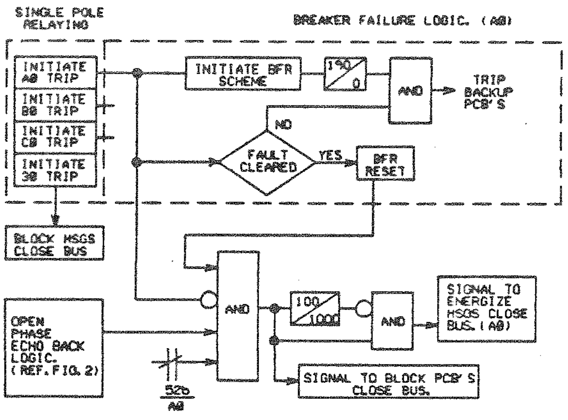

Figure 3. HSGS Signal to Close Logic.

Once the HSGS close bus is energized the X auxiliary relay operates. The X relay energizes the close coil (Ref. Figure 1) and re-trips the line PCB's. Additional interlocks are provided to block the close bus of the line PCB's during this time (Ref. Figure 3). This interlock feature is required to ensure that the line PCB's close bus is not energized accidentally by remote supervisory or recloser maloperation when the HSGS is in the process of closing, or is in the closed position.

HSGS Failure to Close Protection.

Failure to close the grounding switch within a preset time of eight cycles from the Signal to Close command will operate the HSGS Failure to Close Protection logic. The logic in turn will trip the line PCB's three pole and key direct transfer trip (DRT) to the line remote end terminal(s). Figure 4 shows a simplified block diagram depicting a HSGS Failure to Close Protection logic.

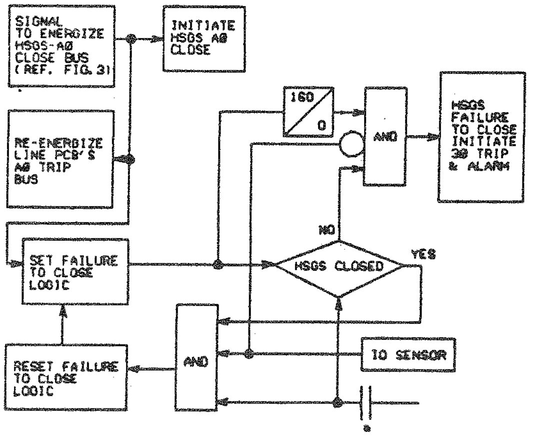

Figure 4. HSGS Failure to Close Protection.

The HSGS close and latch current capacity is 64 kA but the interrupting current capability is only 600 amperes. The secondary arc current therefore, must be below 600 amperes before the HSGS trip cycle can be initiated.

HSGS Overcurrent Protection.

A set of three instantaneous phase overcurrent relays are provided to detect fault current or excessive secondary arc current above 600 amperes. The ground switch contacts in the normally open position are constantly exposed to large travelling voltage surges created by lightning or any abrupt change on the power system. If the overcurrent elements detect fault current in excess of 600 amperes when the ground switch is open, the HSGS Overcurrent protection logic will trip the line PCB's three pole. If the ground switch is in the closed position and the secondary arc current stays above 600 amperes over four cycles, the HSGS Overcurrent Protection logic will again trip the line PCB's three pole. After the line PCB's open the logic will initiate a HSGS trip. Figure 5 shows a simplified block diagram depicting a HSGS Overcurrent Protection logic.

HSGS Failure to Trip Protection.

The same concept and essentially the same basic logic is used for HSGS failure to trip detection as the one developed for a standard Breaker Failure Relay (BFR) scheme. This scheme is familiar to most engineers. In the case of the grounding switch, however, there are additional concerns. Let us

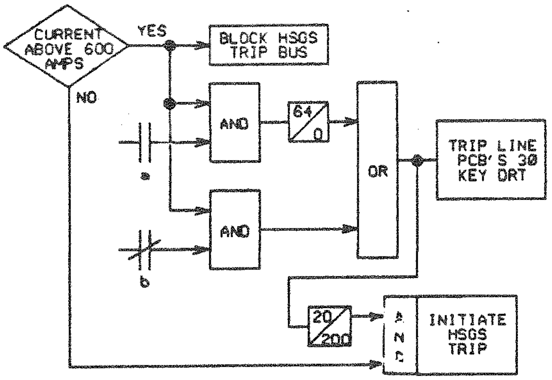

Figure 5. HSGS Overcurrent Protection.

assume that a ground switch trips but fails to clear the secondry arc circuit. Let us also assume that the Failure to Trip Protection scheme correctly identifies the failure and initiates a three pole direct trip to open the line at both end terminals. With the line open at both ends a secondary arc current could still remain due to the adjacent line(s) capacitive coupling. Theoretically, this same phenomenon could happen with a normally open line. If a lightning surge initiates the secondary arc across the grounding switch contact(s) then other lines through capacitive coupling could maintain the arc. The HSGS Failure to Trip scheme, therefore, is designed first to trip the line PCB's; then after the line PCB's are open, trip a motor operated disconnect switch to disengage ther ground switch from the line. Figure 6 shows a simplified block diagram depicting a HSGS Failure to Trip Protection logic.

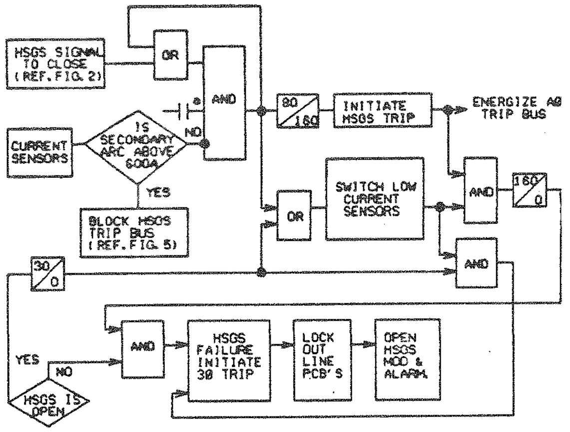

Fig 6. HSGS Failure to Trip Protection.

Note that loss of pressure of the ground switch is also classified as a HSGS Failure mode.

Conclusion:

A. The staged fault test conducted by BPA has proved that the application of high speed grounding switches is a highly effective method for reducing the secondary arc current on long transmission lines.

B. The method has significant economic and operational advantages over conventional approaches.

C. The HSGS requires a very secure, reliable and somewhat complex control and protection scheme to be successful. This paper presented the basic concepts of such a control and protection scheme.

D. BPA intends to install single pole relaying and HSGS on the 525 kV Hanford - John Day and the Hanford - Grand Coulee lines by 10/83.

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