THE APPLICATION OF HIGH SPEED GROUNDING SWITCHES FOR SECONDARY ARC EXTINCTION ON HV/EHV POWER LINES - CONTROL AND PROTECTION

by

J. Esztergalyos
S. L. Wiese
S. H. Ahmed

U.S. Department of Energy
Bonneville Power Administration
Portland, Oregon

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ABSTRACT

This paper has been prepared to aid the electrical industry in the effective and uniform application of high-speed grounding switches (HSGS) on HV/EHV transmission lines.

The paper covers areas such as conventional secondary arc extinction methods on HV/EHV lines with single-phase trip. The four reactor scheme, and the problems arising from its application on parallel, untransposed HV/EHV lines with single-phase trip. Specific problems arising, when lines are terminated in a Gas Insulated Substation (GIS). The paper will describe a newly discovered secondary arc-related fault within the GIS pothead.

Since the installation of High Speed Grounding Switch on the Bonneville Power Administration's (BPA's) 500kV Garrison-Taft No.1&2 lines in 11/14/1985 was the first of its kind, the paper describes the control and protection logic and related system requirements in considerable detail. The complete control and protection schematics of A-phase are included in the APPENDIX. It is expected that the paper will be used by engineers and other technical people who are responsible for designing, operating, or maintaining such systems.

INTRODUCTION

The benefits of single-phase tripping and auto-reclosing are:

A. Improvements in transient and steady state stability.

B. Reduction of switching overvoltages.

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

D. Improvements in system reliability and availability, especially where remote generating stations are connected to load centers with one or two transmission lines.

Single-phase relaying application takes advantage of the fact that most faults on HV/EHV lines are phase-to-ground faults. Some representative statistics of the relative number of different types of faults on HV transmission lines are shown in TABLE I.

TABLE I.
Relative Number of Different Types of Faults on HV Transmission 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 525kV/EHV lines the conductor spacing is increased. Therefore, the percentage of multi-phase faults decreases. The statistics concerning the relative number of different types of faults on the BPA 525kV system are shown on TABLE II.

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

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

Tables I. and II. clearly demonstrate that EHV and future UHV lines benefit the most from single-phase relaying techniques.

BPA's present policy is to install single-phase relaying on all future 525 kV lines and retrofit many of the existing 525 kV lines to single-phase trip. There have been papers published hitherto on the subject of single-phase relaying and various schemes are available. Therefore, this paper will not discuss how one can provide single-phase relaying protection.

DISCUSSION

Successful single-phase relaying requires the high-speed tripping of the faulted phase. The trip, in turn, is followed by a single shot auto-reclose, 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.

Other requirements are less obvious, namely the effect of the electrostatic and electromagnetic coupling of the still-energized phase conductors and parallel line(s) during the dead time of the auto-reclose.

Briefly, the high-current, high-energy primary fault heats and ionizes an arc path through the insulating medium (air) until the faulted phase is tripped.

Afterwards, this heated, ionized arc path:

A. Tends to sustain a secondary arc current (I_s) in the primary arc path and lengthens the time of deionisation, which in turn can prevent successful auto-reclose.

B. Each time I_s extinguishes at a current zero, there is a race between the insulating medium (air) withstand voltage (V_w), and the recovery voltage (V_r), that appears across the secondary arc path as soon as the arc is broken.

   The insulating medium withstand voltage V_w, and its speed of recovery depend on many variables (wind speed, humidity, altitude temperature, etc.). As long as the recovery voltage V_r and its rate-of-rise dVr/dt, is larger than V_w, the secondary arc will reignite and reionize the arc path which can prevent a successful auto reclose.

All methods of secondary arc extinction are directed toward reducing either the magnitude of the secondary arc current I_s or the magnitude of the recovery voltage V_r and its rate of rise, or both.

Accurate calculation of I_s on untransposed, parallel lines require Electro Magnetic Transient Program (EMTP) studies because an open phase action involves many dynamic variables which change with respect to time from the fault inception to the phase opening such as the source voltage phase-angle change, line currents flowing in the sound phases, parallel line loadings and mutual coupling between lines etc.

The secondary arc current I_s on a single, symmetrical, fully-transposed transmission line is basically the phasor sum of two currents maintained by the electrostatic (I_{sc}) and the electromagnetic (I_{sm}) coupling from the two energized phases.

$$I_s = I_{sc} + I_{sm} \qquad [1]$$

CALCULATION OF THE SECONDARY ARC CURRENT VIA ELECTROSTATIC COUPLING

The calculation of I_{sc} for a single, symmetrical, fully-transposed transmission line was developed by Kimbark, Peterson, Dravid, et. al. [1,2,3]. For untransposed line analysis refer to [11,12,13].

Figure 1a. represents a single, symmetrical, fully-transposed transmission line with phase A in an open condition, with a capacitance C_1 between each pair of phases and capacitance C_g from each phase-to-ground. The phase A-to-Ground fault is represented by SW_F. The phasor of the effective voltage is shown in Figure 1b.

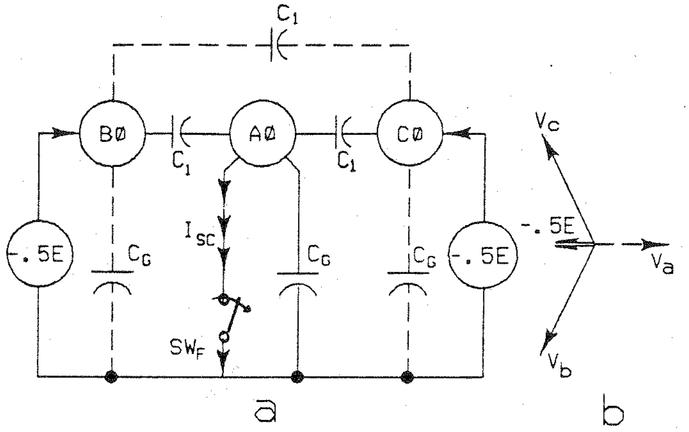


Figure 1. Electrostatic Coupling Diagram of a Single, Symmetrical, Fully Transposed Transmission Line.

The Thevenin equivalent circuit derived from Figure 1. is shown in Figure 2a. It is achieved by folding phase C to phase B.

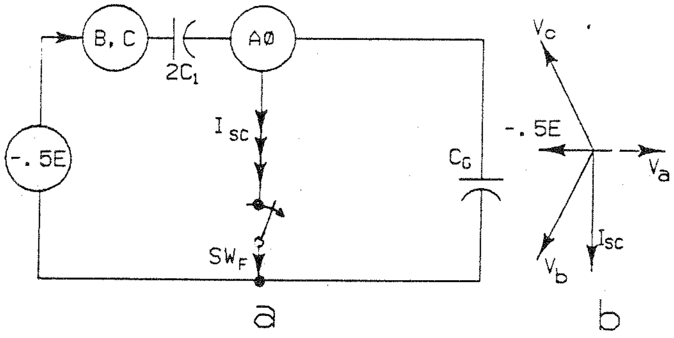


Figure 2. Electrostatic Coupling Thevenin Equivalent Diagram of a Single, Symmetrical, Fully Transposed Transmission Line.

The magnitude of the secondary arc current due to electrostatic coupling is in direct proportion to the line voltage and the line length. From inspection of Figure 2a with SW_F closed:

$$I_c = -.5E \times \frac{-2}{1/j\omega C_1} = E\, j\omega C_1 \qquad [2]$$

Typical secondary arc values for 500-kV lines are I_{sc} = 20 amperes per 100 miles. The phase relationship between the effective phase voltages and I_{sc} is shown in Figure 2b.

CALCULATION OF THE RECOVERY VOLTAGE

The magnitude of the recovery voltage (V_r) is directly proportional to the line voltage and the relative values of C_1 and C_g. Consequently, V_r does not vary with line length.

From inspection of Figure 2a. the recovery voltage on phase A with SW_F open:

$$V_r = -.5E \times \frac{1/-jwCg}{(1/-jwCg)+(2/-jwC_1)} \qquad [3]$$

$$V_r = -.5E \times \frac{Cg}{Cg + 2C_1} \qquad [4]$$

The recovery voltage V_r and the secondary arc current I_s versus line length on a single 500kV line without shunt compensation is shown in Figure 3.

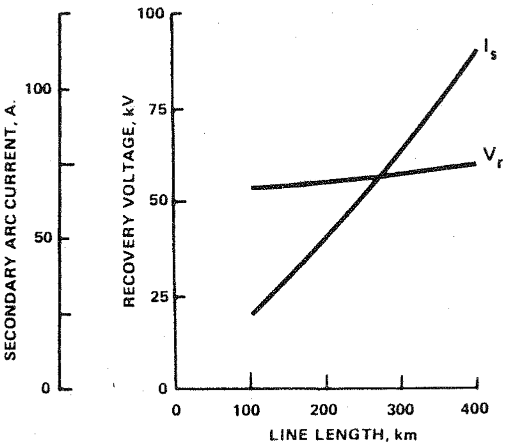


Figure 3. Recovery Voltage and Secondary Arc current versus Line Length on a single 500 kV line without shunt compensation.

Closing the HSGS at one or both end terminals reduces the value of Cg, which in turn will reduce the value of V_r to a point where the recovery voltage cannot sustain the secondary arc current I_{sc}.

The reduced recovery voltage profile for a single 500kV, 300km long transmission line with HSGS closed at both end terminals on the open phase is shown in Figure 4. The recovery voltage profile for a single, symmetrical, fully transposed transmission line with HSGS closed at only one end terminal on the open phase is shown in APPENDIX C.

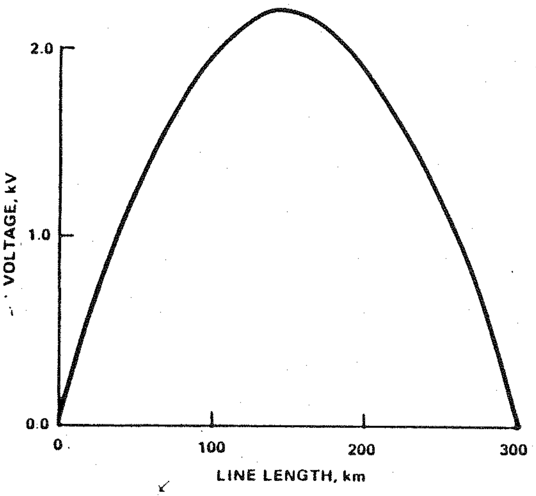


Figure 4. The Recovery Voltage profile for a single 500kV, 300km long transmission line with HSGS closed at both end terminals on the open phase.

CALCULATION OF THE SECONDARY ARC CURRENT VIA ELECTROMAGNETIC COUPLING

The calculation of the Ism on the 500kV Garrison-Taft No 1 and 2 lines required EMTP studies because open phase action on parallel, untransposed lines involves many dynamic variables. However, with some judicious assumptions one can calculate the maximum Ism on a single line.

During single-phase opening, the reactance values of the system change with respect to time depending on whether:

1) The moment of the fault is taken as the criterion.
2) The moment just after the fault is the criterion.
3) Some time after the fault has taken place is the criterion.

In case 1) the reactance is the subtransient reactance X''_d.

In case 2) the reactance is the transient reactance X'_d.

In case 3) the reactance is the synchronous reactance X_d.

o by definition: $X''_d \leq X'_d \leq X_d$ [5]

Therefore, for the "worst case" type of calculation, the X"d values should be selected on the assumption that the I_{sm} magnitudes that are calculated with the X"d reactance will always be more than the current magnitudes calculated with the X'd and Xd values.

In practical terms, one should select the maximum steady state load flow the positive, negative and zero sequence subtransient reactance (X"d) values for the sources as well as the line parameters that are readily available from system fault data.

For example: A simplified two machine diagram representing the 500kV Garrison - Taft No 1 line with the No 2 line out-of-service is shown in Figure 5.

o Assume that the voltage at the end terminals are equal.

$$E_1 = E_2 = 1 \text{ p.u.} \qquad [6]$$

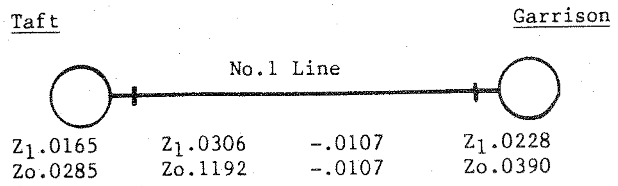


Figure 5. 500kv Garrison - Taft No 1. line -Two Machine Diagram

- For the "worst case" condition assume that the positive sequence MVA transfer is equal to the maximum steady state load flow i.e.

$$\text{Steady state MVA} = 1000\ \text{MVA} \qquad [\ 7]$$

1000 MVA in per unit on a 100MVA base.

$$\text{MVA pu} = \frac{1000}{100} = 10\ \text{p.u.} \qquad [\ 8]$$

- by definition

$$\text{MVA} = \frac{E^2 \times \sin\delta}{X_1} \qquad [\ 9]$$

$$\text{therefore} \quad 10\ \text{pu} = \frac{1 \times \sin\delta}{.0592} \qquad [10]$$

from which we can calculate the sin δ

$$\sin\delta = .592 \qquad [11]$$

The sequence network Interconnection for phase A open is shown in Figure 6.

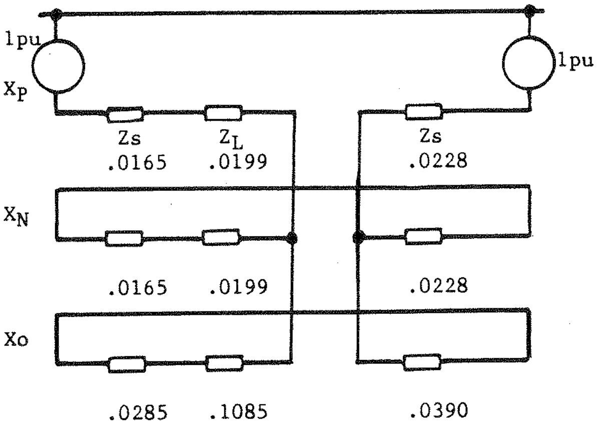


Figure 6. 500kv Garrison - Taft No 1. line -Two Machine Diagram with One Phase Open

Assume that the power angle sine δ does not change between the two sources when one phase is opened. The system symmetrical component configuration is positive sequence plus a parallel configuration of negative and zero sequence network, which with one phase open will reduce the power transfer to:

$$\text{MVA} = \frac{E^2 \times \sin\delta}{\text{Xpu}} \qquad [12]$$

$$\text{where Xpu} = \text{Xp} + \frac{1}{\frac{1}{X_N} + \frac{1}{\text{Xo}}} \qquad [13]$$

$$\text{where Xpu} = .0592 + \frac{1}{\frac{1}{.0592} + \frac{1}{.1760}} \qquad [14]$$

$$\text{Xpu} = .0592 + .0443 = .1035\text{pu} \qquad [15]$$

From inspection of Figure 6. the per unit distribution of the positive sequence current during open phase is the same as the MW pu.

$$I_1 = \frac{1 \times \sin\delta}{\text{Xpu}} \qquad [16]$$

From which

$$I_1 = \frac{1 \times 0.592}{.1035} = 5.72\text{pu} \qquad [17]$$

% distribution of negative sequence current I_2

$$I_2 = \frac{.0443}{.0592} \times 100 = 75\% \qquad [18]$$

or

$$I_2 = .75 \times 5.72 = -\ 4.29\text{pu} \qquad [19]$$

% distribution of zero sequence current Io

$$\text{Io} = \frac{.0443}{.1760} \times 100 = 25\% \qquad [20]$$

or

$$\text{Io} = .25 \times 5.72 = -\ 1.43\text{pu} \qquad [21]$$

from which

$$I_B = a^2 I + aI_2 + \text{Io} = -2.15 - j8.66\text{pu} \qquad [22]$$

$$I_C = aI + a^2 I_2 + \text{Io} = -2.15 + j8.68\text{pu} \qquad [23]$$

The relationship between I_B and I_C and the driving current Idr is shown in Figure 7.

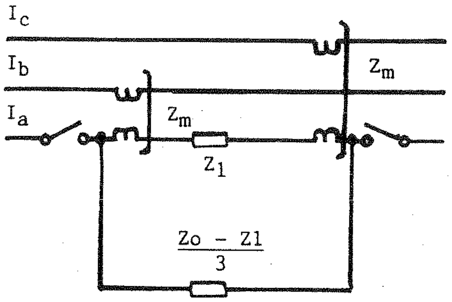


Figure 7. 500kv Garrison - Taft No 1. line Driving Current One-Line Diagram.

- From which the driving current Idr:

$$I_{dr} = I_B + I_C = 2 \times (-2.15) = -4.3\text{pu} \qquad [24]$$

- Note that the driving current Idr is the same as $3I_o$.

$$\text{Idr} = 3I_o \qquad [25]$$

- The driving voltage Vdr induced in phase A via electromagnetic coupling Z_m and driving current $3I_o$.

$$\text{Vdr} = 3I_o \times X_m \qquad [26]$$

- By definition:

$$X_1 = X_2 = X_P + X_m \qquad [27]$$

and

$$X_o = X_p + 2X_m \qquad [28]$$

o [Note: X_p and X_m are defined from Carson's equations].

from which

$$X_m = 1/3(X_o - X_1) = 1/3(.1085-.0199) = .0295\text{pu} \qquad [29]$$

from which the driving voltage Vdr

$$Vdr = -4.3 \times .0295 = .127 \text{ pu} \qquad [30]$$

The Thevenin Equivalent Diagram of a single, symmetrical, fully-transposed transmission line showing both the Electrostatic (Isc) and the Electromagnetic (Ism) Coupling with open phase A shorted by HSGS1 and HSGS2 at both end terminals is shown in Figure 8.

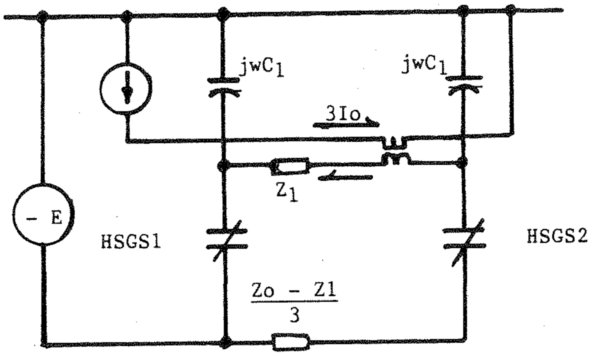


Figure 8.Thevenin Equivalent Diagram showing the Electrostatic (Isc) and the Electromagnetic (Ism) Coupling Driving Current with open phase A grounded at both ends.

The secondary arc current I_{sm} at the HSGS1 end terminal:

$$Ism = \frac{Vdr}{1/3(X_1+X_2+Xo)_{line}} \qquad [31]$$

$$Ism = \frac{.1270}{1/3(.1483)} = 2.57 \text{ pu.} \qquad [32]$$

The secondary arc current I_s at the HSGS1 end terminal:

$$Ism = 2.57\text{pu} \times 110\text{amp/pu} = 282 \text{ amp} \qquad [33]$$

$$I_s = I_{sc} + I_{sm} = 20 + 282 = 302 \text{ amp} \qquad [34]$$

The secondary arc current I_s at the HSGS2 end terminal:

$$I_s = I_{sc} - I_{sm} = 20 - 282 = 262 \text{ amp} \qquad [35]$$

The current through the HSGS for different line loadings a single 500kV line is shown in Figure 9.

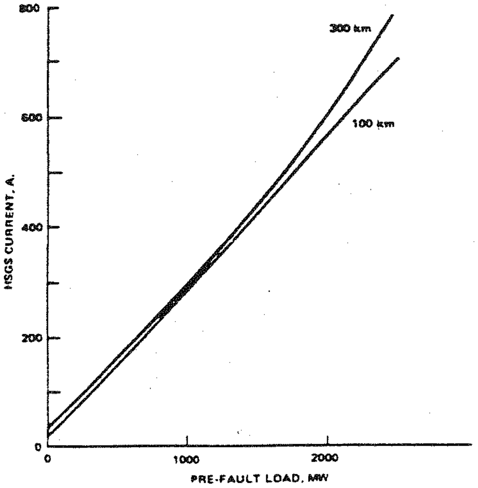


Figure 9. Current through the HSGS for different line loadings and lengths for a 500kV line.

CONVENTIONAL METHODS OF SECONDARY ARC EXTINCTION

Table III. indicates the following probable performance for lines without supplemental arc extinction measures.

TABLE III.
The probability of successful single-phase auto-reclosure without supplemental arc extinction devices.
Line Length (Mi)

Line to Line Voltage (kV)	Successful Range	Doubtful Range
230	0-300	300 - 500
345	0-140	140 - 260
500	0-60	60 - 100
765	0-50	50 - 80

If the line is longer, additional measures must be taken to reduce the secondary arc. There are basically two conventional methods for reducing the Secondary Arc Current:

A. Permanently connected banks of four reactors.

The scheme was first proposed by Knudsen [4] and again by Kimbark [1]. This scheme has been successfully applied worldwide and is familiar to most engineers.

Advantages: Proven design, simple implementation, three-phase reactors may already exist.

B. Modified, selectively-switched, four reactor scheme.

This scheme is used on long untransposed (765kV) lines [11,12] where four reactor schemes are not effective to extinguish the secondary arc. 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.

FOUR REACTOR SCHEMES ON SINGLE LINES SPECIFIC PROBLEM

One disadvantage is the high cost of four reactors. In new substations where three shunt reactors are required for voltage regulation, the additional cost of the fourth grounding reactor is relatively small. In cases where an existing line is being converted from three-phase to single-phase trip, the existing three reactors (if any) neutral bushing BIL rating is not sufficient. Therefore, the three-reactor scheme must be replaced with a new four-reactor scheme at a significant cost.

Another disadvantage is the operational problems associated with system voltage control when the line is heavily loaded. The three-reactor scheme 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 disadvantages of a selectively-switched four reactor scheme is the high cost of four reactors, the cost of a high speed shunt reactor switch, and the cost of the additional control scheme. 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.

SHUNT REACTOR SCHEMES ON PARALLEL LINES

One significant problem, is that the standard four-reactor scheme is essentially a single point device, and it may not work where the fourth reactor can be detuned by lines that are constructed in parallel.

To solve the problem, a new scheme was proposed by Kimbark [2] but has never been used on a power system.

This design uses 3 shunt capacitor banks and 9 shunt reactors to neutralize the 15 inter-conductor capacitances. The disadvantages of a 3 shunt capacitor, 9 shunt reactor scheme is the high cost, plus the complexity of the control scheme.

Shunt Reactor Scheme on GIS-Terminated Parallel Lines

A new secondary arc-related problem within the GIS pothead is described which will not extinguish itself if the GIS-terminated line runs parallel to other lines. The problem is discussed in detail in the APPENDIX, in Section A.

HIGH-SPEED GROUNDING SWITCH SCHEME

This scheme involves the application of a high-speed grounding switch in each phase at one or both ends of the line.

The HSGS is closed onto the faulted phase after the circuit breaker pole on that phase opens, and vice versa for reclosing. In principle, the HSGS reduces the voltage from the open phase on the line and, therefore, practically removes the driving voltage behind the secondary arc. [8, 9]

Advantages: Low cost. For system operation the HSGS provides high flexibility. Shunt reactors can be placed at any point of the system since they are not a part of the single-phase tripping scheme.

Disadvantages: More complex Control and Protection scheme. Additional operation and maintenance cost.

A. HSGS Hardware Specification

The hardware specification of the HSGS at Taft Substation is shown in TABLE IV.

TABLE IV.

Ground Switch: Hitachi Type	FGH
Rated Voltage:	550kV
Max. Operating Voltage:	550kV
BIL:	1550kV
Recovery Voltage:	78kV
Interrupting Current:	700 Amp
Close and Latch Current:	64kA
CT Ratio:	600/5 -C400

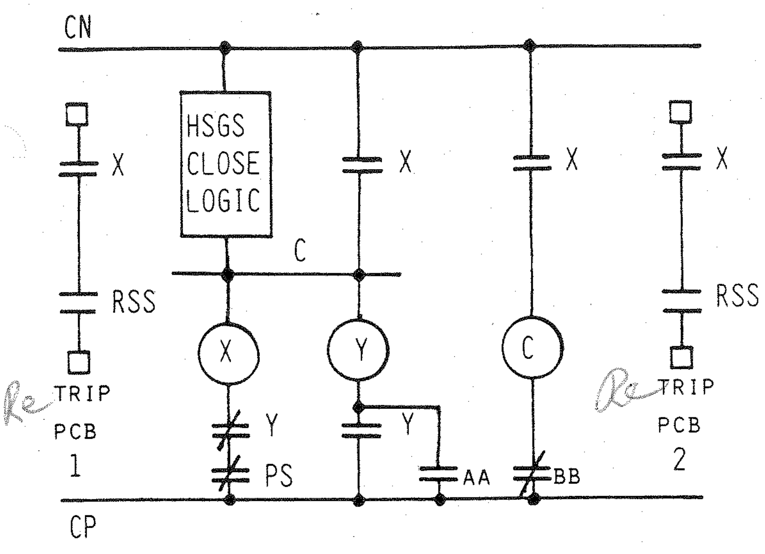
The hardware specification of the HSGS at Garrison Substation is described in the APPENDIX in Section B.

Additional performance requirements are described in more detail below.

B. HSGS Absolute Close Speed

HSGS absolute closing speed was selected at five cycles. Figure 10. illustrates the necessity of careful close speed selection.

Note that the line breakers PCB 1 and 2 trip bus are energized when the HSGS close coil, C, is energized by the X closing relay. 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, minimizing the possibility of closing the HSGS when the adjacent line breakers are in the opening cycle. 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 auto-reclose operation.



LEGEND:
C- CLOSE COIL
Y- ANTI PUMP RELAY
X- CLOSING RELAY
PS- GAS PRESSURE
AA- PCB A CONTACT
BB- PCB B CONTACT
RSS- RELAY SELECTOR SWITCH

Figure 10. HSGS Simplified Close Bus Diagram.

C. HSGS Absolute Trip Speed

The HSGS is provided with two trip coils 52TC1 and 52TC2 per phase. The HSGS absolute trip speed is two cycles.

The trip speed is not as critical. Therefore, it may be as long as five cycles, but a longer time delay is not recommended since it effects the coordination of the auto-reclose operation.

HSGS CONTROL AND PROTECTION

The HSGS Control and Protection Scheme required the development of new control logic, some of which are the "mirror images" of existing concepts. The complete scheme is quite extensive, including logic as well as mechanical interlocks at every step of the close and trip cycle.

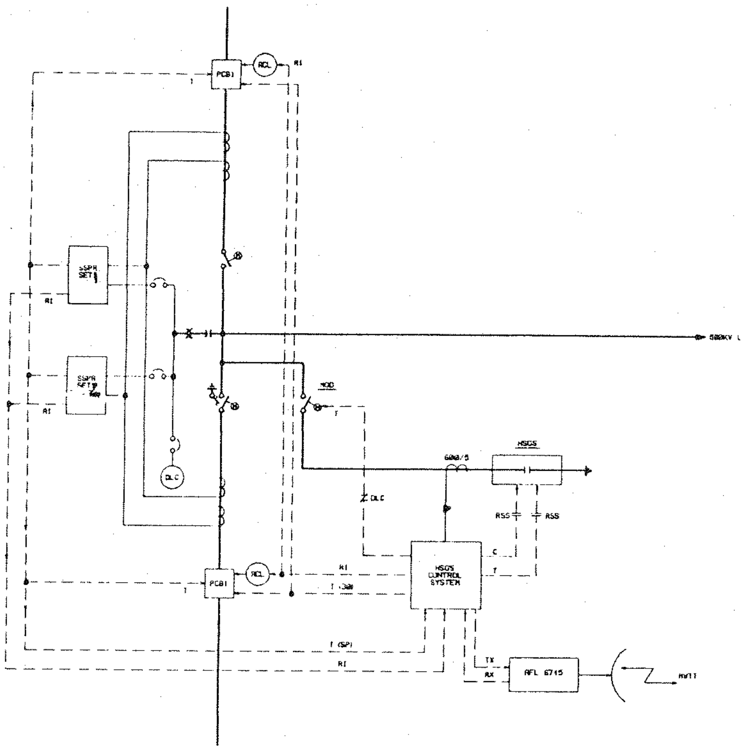
The one-line diagram of a 500 kV HSGS installation at Taft Substation is depicted in Figure 11.

A. HSGS Main Hardware

The main hardware is described as follows:

- One High Speed Ground Switch (HSGS 03E)
- One Motor Operated Disconnect switch (MOD 3E-1)
- One Grounding Switch (G3E-1)
- One HSGS Control System

The same basic hardware is installed at the other end of the line at Garrison Substation.



Legend:

SSPR	Static Single Pole Relay
DLC	Deadline Voltage Check
RCL	Recloser
T(SP)	Trip Single Phase
T(3PH)	Trip Three Phase
RI	Reclose Initiate
RSS	Relay Selector Switch
TX/RX	Transmit/Receive
MWTT	Audio Transfer Trip (FS via Microwave Radio)
C	HSGS Close
T	HSGS Trip

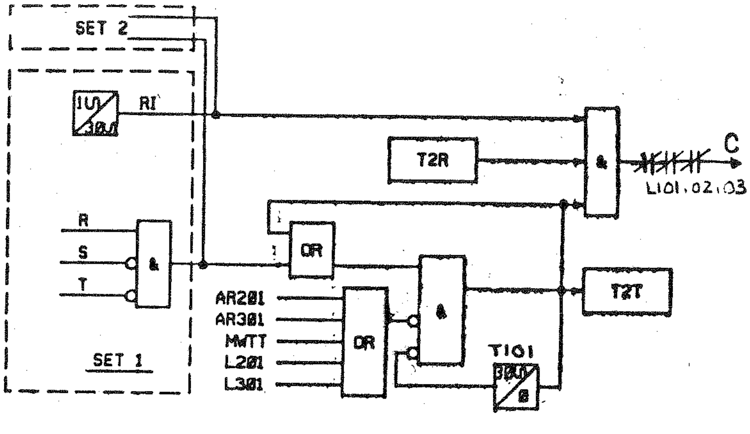
Figure 11. HSGS One Line Diagram.

500 kV LINE SINGLE PHASE RELAYING

The 500 kV Garrison-Taft No.1 & 2 lines Single-Phase Relaying protection consist of two relay terminals operating in a conventional direct-underreach, permissive-overreach, transfer trip mode over microwave radio. The single-phase relaying logic is used for the faulted phase selection.

The operation of the line relays single-phase trip output (TA or TB or TC) signals and the operation of the Reclose-Initiate (RI) signal is sent to the HSGS Close Control Logic, indicating a single-phase trip.

Figure 12. shows a one-line diagram of the line relay output to the HSGS A-phase close control logic.



Legend:

Set No.1	GE type SLYP/SLCN
Set No.2	ASEA type RALDA/RAZOA
T2T/T2R	Permissive Tone2 via Microwave radio Transmit/Receive
AR101,201,301	Hi speed aux. relays A,B,C phase
L101,201,301	Aux. Latching relays A,B,C phase
C	Close Bus
X101,02,03	HSGS Close Relay A,B,C phase
T101	Aux. Time delay relay.

Figure 12. HSGS A-phase. Close Control Logic.

HSGS CONTROL - CLOSED POSITION

A. HSGS Signal-to-Close - Normal Operation.

Briefly, the HSGS close control logic in Figure 12. will sample-and-hold the A-phase trip signal for 30 cycles via T101, and transmit a permissive microwave signal via T2T, to the remote end terminal(s). HSGS signal-to-close is not initiated, until the permissive signal T2R is received from the remote end terminal(s) indicating an open phase at the remote end.

Once the HSGS close bus C is energized, the X101 auxiliary relay operates. The X101 relay energizes the A-phase close coil 57/CC and retrips the line PCB's 1 & 2. Additional interlocks are provided (via the X101 relay) that momentarily de-energize the close bus of the line PCB's during the HSCS closing cycle. This interlock feature is required to ensure that the line PCB's will not close accidentally by remote supervisory signal-to-close, or reclose misoperation when the HSGS is in the process of closing, or it is in the closed position. For a more detailed description of the close control logic and the schematic diagram, refer to BPA DWG. No. 234796 sheet No.2

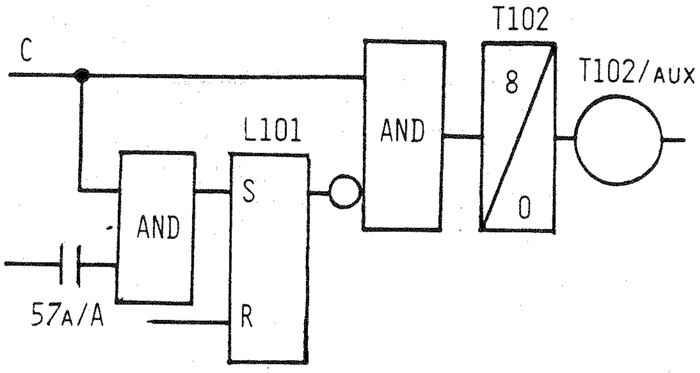
B. HSGS Failure-to-Close Protection.

The HSGS failure to close protection logic consists of the L101 latching relay, T102 timer and the T102 auxiliary trip relay.

Failure to execute a HSGS close within a preset T102 time of eight cycles from the signal-to-close command, will operate the HSGS failure-to-close Protection logic.

The HSGS failure-to-close protection logic in turn will trip the line PCB's three-phase, key Direct Microwave Transfer Trip (MWTT) to the line remote end terminal(s).

Figure 13. shows a simplified block diagram depicting the HSGS failure-to-close protection logic. For detailed schematic refer to BPA DWG. No. 234796 sheet 2.



LEGEND:

C- HSGS CLOSE SIGNAL

57A/A- HSGS "A" CONTACT A PHASE

T102- FAILURE TO CLOSE TIMER

T102/AUX- T102 AUXILIARY TRIP RELAY

L101- AUX.LATCHING RELAY SET/RESET

Figure 13. HSGS A-phase. Failure-to-Close Protection.

C. HSGS in the closed position. Signal-to-Trip Logic - Normal Operation.

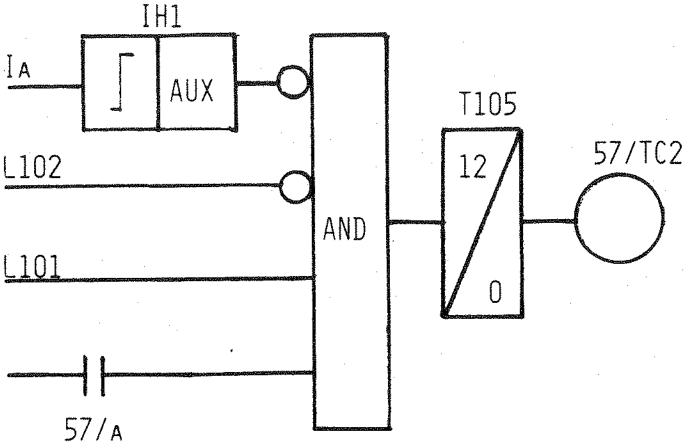
The signal-to-trip logic trips the HSGS No.2 (57/TC2) trip coil. The logic consists of IH1 high-set instantaneous overcurrent relay, IH1/AUX auxiliary relay and T105 time-delay relay. The logic is supervised by L101, L102 and the HSGS 57/a contact.

During normal operation the HSGS is tripped after 12 cycle time delay measured from the time when the HSGS, 52a contact closes. The "HSGS on" time delay is set via the T105 timer. The 12 cycle setting was determined from field test as the time necessary for the HSGS to be in the closed position to extinguish the secondary fault arc. Post-fault analysis of the oscillograph data measuring the length of the deionisation time of the secondary arc is recommended for more accurate T105 setting.

The signal-to-trip logic one line diagram is shown in Figure 14. For detailed schematic refer to BPA DWG. No. 234796 sheet 3.

D. HSGS in the Closed Position - HSGS Failure to Trip Protection.

The same concept, and essentially the same basic logic is used for the HSGS failure to trip detection as the one developed for a standard Breaker Failure Relay (BFR) scheme.



LEGEND:
IH1- HI SET INSTANTANEOUS
OVERCURRENT RELAY W/AUX TRIP OUTPUT
57/TC2- NO.2, TRIP COIL
T105- "HSGS ON" TIMER
L101,L102 AUX.LATCHING RELAYS
57/A- HSGS "A" CONTACT A PHASE

Figure 14. HSGS A phase. Signal-to-Trip Logic. Normal Operation.

The BFR scheme consists of a T112 timer, set for 10 cycles, and a secondary arc current detector I_A which supervises the T112 timer. A failure to trip the grounding switch within 10 cycles will operate the HSGS failure-to-trip protection logic.The logic T112 contact trips the L102 auxiliary trip relay which in turn will trip the line PCBs three pole, key MWTT to the remote end terminal(s) and isolate the ground switch by opening the motor operated disconnect switch (MOD3E-1).

For a detailed schematic of the failure-to-trip protection logic, refer to BPA DWG. 234796 sheet No.3

HSGS CONTROL - OPEN POSITION

A. Line Reclose Initiate Signal - Normal Operation.

After a successful HSGS close that is followed by a trip via T105 timer, the secondary arc current, Is, is eliminated. The last control phase of the HSGS control logic is a Reclose Initiation (RI) signal to the line PCBs.

Briefly, the signal-to-trip output of T105 timer is captured with a sample-and-hold (S/H, AR102 & T107) logic. The S/H output and a 57b contact starts the line RI timer T106.

The T106 timer's 20-cycle time delay setting is nominal. It can be re-adjusted in the field so the line PCBs single-phase reclose time does not exceed 45-55 cycles. The dropout time of the reclose initiate signal is adjusted by the S/H timer, T107.

The reclose initiate logic is shown in Figure 15. For detailed schematics refer to Line Reclose Initiate - Normal Operation on BPA DWG 234796 sheet No.3

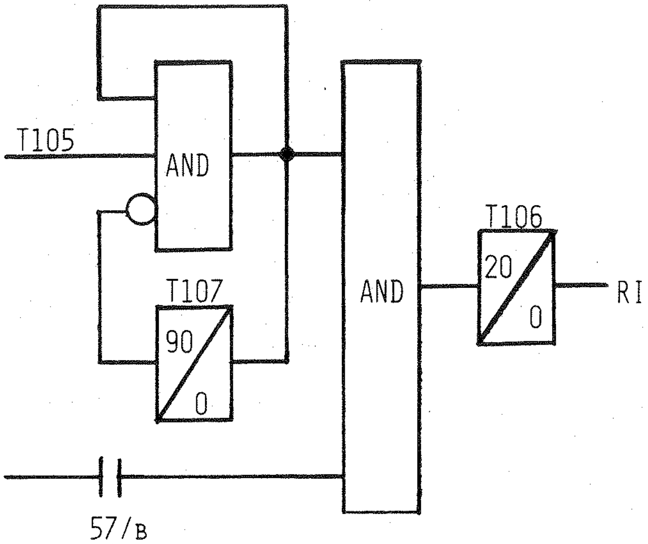


Figure 15. HSGS A-phase. Line Reclose-Initiate Logic.

HSGS PROTECTION

A. Overcurrent relay setting.

A set of two instantaneous overcurrent relays are provided for each phase. One overcurrent relay I_A is set low to detect secondary arc current via electrostatic coupling. The other overcurrent relay I_{H1} is set high to detect fault currents.

The recommended low-set overcurrent relay setting is:

$$I_A = .8 \times Isc = 16 \text{ amps} \qquad [36]$$

The recommended high-set overcurrent relay setting is:

$$I_{H1} = 2 \times (Ism + Isc) = 604 \text{ amps} \qquad [37]$$

B. Overcurrent Protection - HSGS Open.

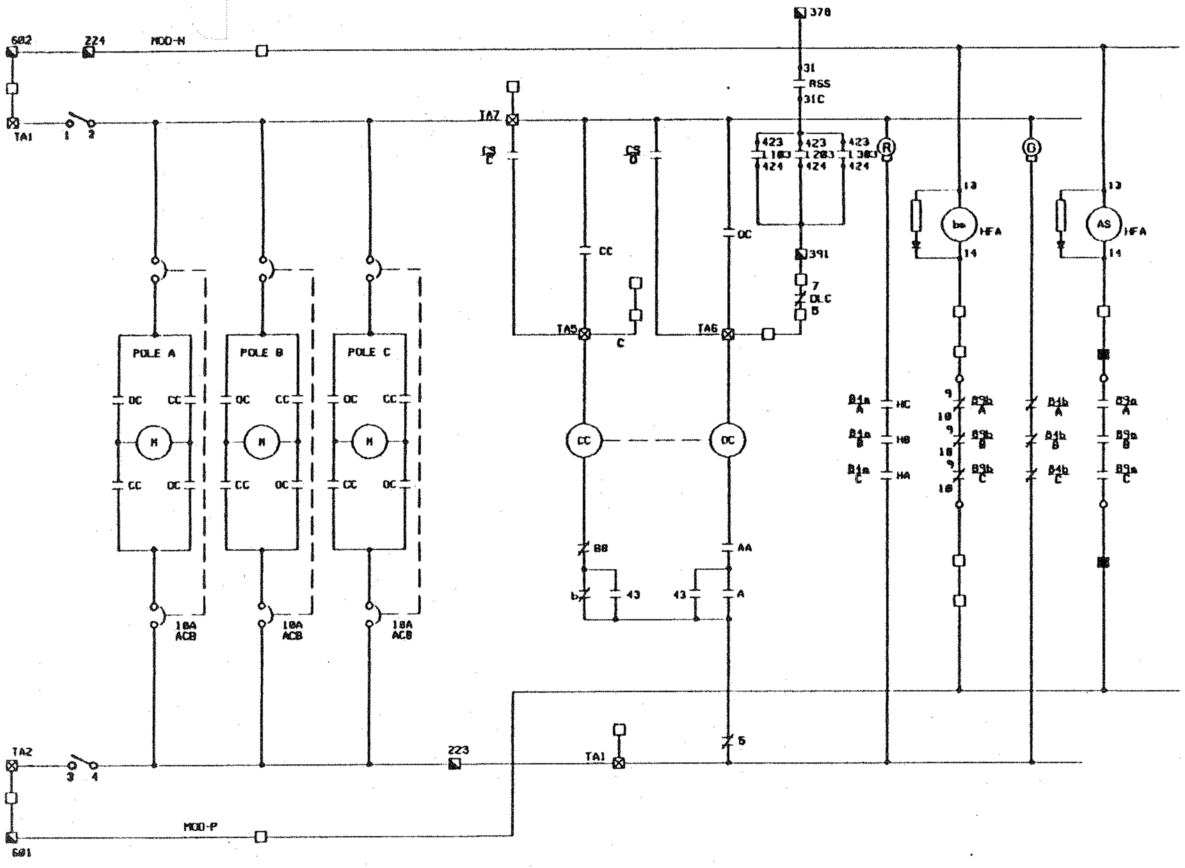
The ground switch contacts in the normally open position are constantly exposed to traveling voltage surges created by lightning or abrupt changes on the power system.

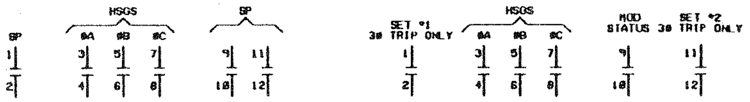
If fault current is detected, the I_{H1} overcurrent relay will trip the L103 auxiliary latching relay after the T110 time delay (2 cycles).

If the secondary arc current, Is, is detected, the I_A overcurrent relay will trip the L103 auxiliary latching relay after the T111 time delay (10 cycles).

The L103 auxiliary, latching relay in turn will trip the line PCBs three pole, key direct transfer trip (DTT) to the remote terminals, and isolate the ground switch by opening MOD3E-1.

For a detailed schematic of the overcurrent protection logic with the HSGS open, refer to BPA DWG. 234796 sheet No.3 and 4.





LEGEND:

☐	TERMINAL ON CONTROL PANEL INDOOR.
☒	TERMINAL IN THE MOD CABINET OUTDOOR.
◩	TERMINAL ON HSGS CONTROL PANEL INDOOR.
BB	LIMIT SWITCH,CLOSED EXCEPT IN MECH.FINAL CLOSED POSITION.
AA	LIMIT SWITCH,CLOSED EXCEPT IN MECH.FINAL OPEN POSITION.
5	CUTOUT SWITCH FOR MANUAL OPERATION.
DLC	DEAD LINE CHECK.
CS	CONTROL SWITCH.
CC	CLOSE CONTACTOR.
OC	OPEN CONTACTOR.
89a	LIMIT SWITCH AT BASE OF ROTATING INSULATOR STACK,CLOSED WHEN DISC.SW.IS IN FULLY CLOSED POSITION.
89b	LIMIT SWITCH AT BASE OF ROTATING INSULATOR STACK,CLOSED WHEN DISC.SW.IS IN FULLY OPEN POSITION.
43	SELECTOR SWITCH
84a,b	MOTOR OPERATOR AUX SWITCH
▨	TERMINAL ON TERMINATION FRAME

DRAWING NUMBER	SHEET	TITLE
		REFERENCE DRAWINGS

1		962-313	AS CONSTRUCTED			
NO.		W.O.	COMPUTER REVISION ONLY	BY	DATE	APPROV

C=CONTRACT CONSTRUCTION / F=FORCE ACCOUNT CONSTRUCTION / R=RECORD

DESIGN	ENGINEERING
DESIGN JE	
DRAWN GSB	ENGR TE
CHKD	CHKD
SUB	SUB
SUB JVE	SUB

REC

REC

APPR VICKIE VANZANDT

DATE 4/26/83

UNITED STATES DEPARTMENT OF ENERGY
BONNEVILLE POWER ADMINISTRATION
HEADQUARTERS, PORTLAND, OREGON

500KV HIGH SPEED
GROUNDING SWITCH
MOD CONTROL SCHEME

SERIAL	SOURCE	SIZE	SHEET	REVISION
234796	NRC	A1	4	1