**Final Draft Report**



**Single Phase Auto-reclose**

**and Neutral Grounding Reactor study**

**Manitoba HVDC Research Centre**

211 Commerce Drive

Winnipeg,MB R3P 1A3

CANADA

[www.pscad.com](http://www.pscad.com)

|  |  |  |
| --- | --- | --- |
| **Rev** | **Description** | **Date** |
| **0** | Draft issue | 2010-09-30 |
|  |  |  |
|  |  |  |

Contents

[1. Introduction 3](#_Toc328602791)

[2. The Line End and Neutral Grounding Reactors (NGR) Scheme on the lines 4](#_Toc328602792)

[3. The impact of the line reactor and the NGR on the arc extinction time 6](#_Toc328602793)

[3.1. General 6](#_Toc328602794)

[3.2. Arc Model 6](#_Toc328602795)

[3.2.1. Initial arc length (Larc) 6](#_Toc328602796)

[3.2.2. Magnitude of the primary arc (Ip) 6](#_Toc328602797)

[3.2.3. Magnitude of the secondary arc (Is) 7](#_Toc328602798)

[4. Simulation results 8](#_Toc328602799)

[5. References 9](#_Toc328602800)

[6. Appendix 1 Calculation of the NGR – Method 01 10](#_Toc328602801)

[7. Appendix 2 Calculation of the NGR based on the Basic Impulse Insulation Levels (BIL) 11](#_Toc328602802)

# Introduction

Although three-phase bus fault is the most serious fault on transmission lines, experiences and statistical data indicate that the Single Phase to Ground (SLG) is the most common fault, especially in EHV transmission systems.

Single phase switching is being used to enhance the stability, power transfer capabilities, reliability, and availability of a transmission system during a single phase ground fault.

When a single-phase to ground fault occurs, the faulted phase is isolated from both ends by the related protective relays and single pole breakers. The faulted conductor (line) is capacitively and inductively coupled to the two sound conductors and other conductors of parallel circuits (ex. Double circuit lines), which are still energized at approximately normal circuit voltage and carrying load current. This coupling has two effects [1]:

* Before the extinction of the fault arc, it feeds current to the fault and maintains the arc.
* After the arc current becomes zero, the coupling causes a recovery voltage across the arc path. If the rate of rise of recovery voltage is too great, it will reignite the arc.

The arc on the faulted phase conductor after it has been switched off is the secondary arc. Recovery voltage is the voltage across the fault path after the extinction of the secondary fault arc and before re-closure of the circuit breakers.

Extinction of the secondary arc depends on its current, recovery voltage, length of the arc path, wind velocity, and perhaps on other factors. If the secondary arc is extinguished completely before the reclosing, reclosing would be successful. In order to have successful fast re-closing, different methods have been applied to extinguish the arc faster. One of the common methods is to use a single-phase neutral grounding reactor (NGR) in the neutral point of the line reactors, when the transmission line is compensated with line reactors [1]-[3].

The purpose of this study is to evaluate the nature of the secondary arc and its extinction time for faults on the 380 kV double circuit line. Specifically, the impact of operating the power network with line end reactors out of service was under consideration.

# The Line End and Neutral Grounding Reactors (NGR) Scheme on the lines

The NGR is used to cancel the capacitive component of the secondary arc current [1]. In order to cancel the capacitive current, the inductive and capacitive branches must resonate. By satisfying this condition, the appropriate amount of neutral reactor is achieved, as shown in Appendix 1:Calculation of the NGR – Method 01. Installation of this reactor is effective when capacitive coupling becomes symmetrical through phase transposing. the line is transposed in 5 segments. The NGR should meet the Basic Impulse Insulation requirements as outlined in Appendix 2: Calculation of the NGR based on the Basic Impulse Insulation Levels (BIL)

The installed NGR of 900 Ω agrees with the design criteria of both Appendix 1: Calculation of the NGR – Method 01 and Appendix 2: Calculation of the NGR based on the Basic Impulse Insulation Levels (BIL).

**Reactors:**

Four 80 MVAR (1800Ω) three-phase reactors each with a 900Ω NGR are installed at each end of the double circuit. In addition to these, the double circuit 380 kV line is also equipped with line end reactors at bus2 (Figure 1).

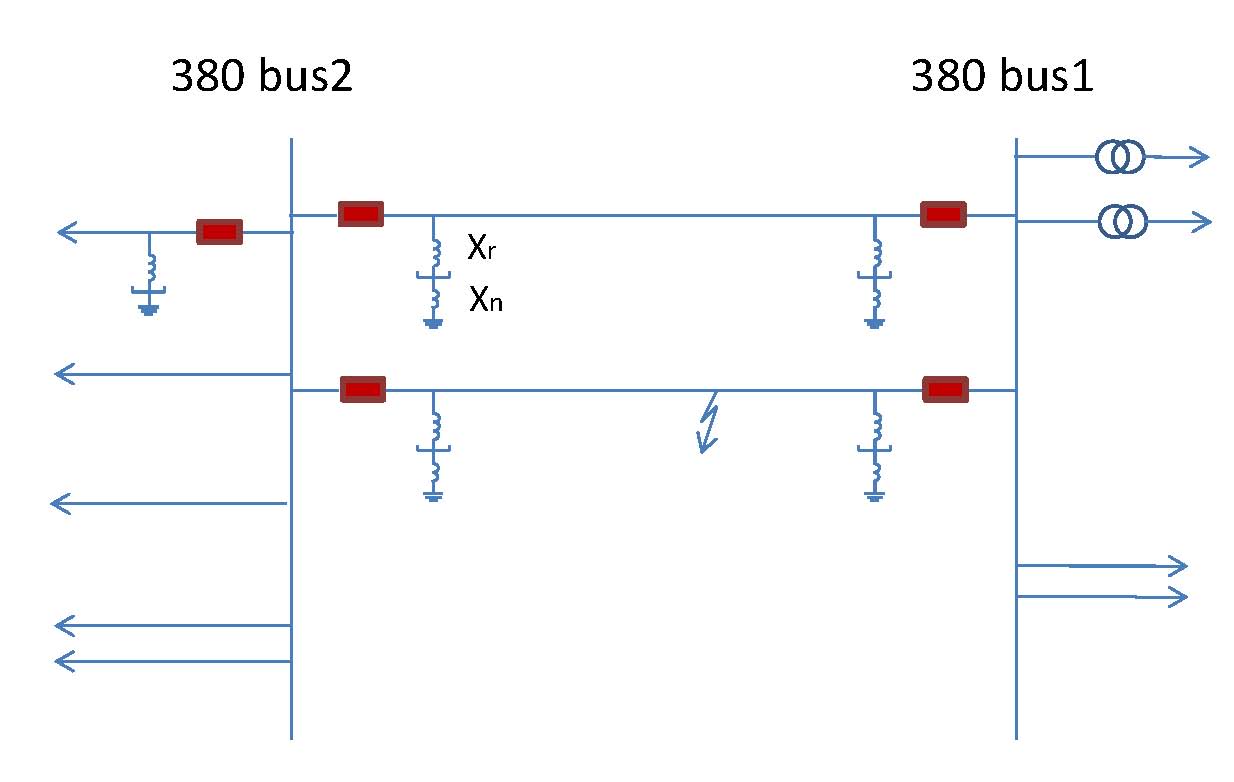


Figure The reactors at bus1 and bus2 substations

The PSCAD implementation of the double circuit line and arc model used in the simulation studies is shown in Figure 2.



Figure The 380kV double circuit

# The impact of the line reactor and the NGR on the arc extinction time

## General

Simulation studies were performed to examine the effect of the line reactor and NGR at the double circuit transmission line on the secondary arc extinction time and the recovery voltage. The secondary arc extinction time and the recovery voltages were calculated under different conditions. These include:

* Different fault locations along the double circuit line
* Line end reactors (and NGR) of the line in or out of service
* Impact of line end reactors on the line
* Impact of ‘initial’ arc length

## Arc Model

The arc model used in this PSCAD/EMTDC study is based on the model proposed in [5]. The following parameters that influences the arc extinction time are inputs to this mathematical model.

* Initial arc length (Larc)
* Magnitude of the primary arc (Ip)
* Magnitude of the secondary arc (Is)

### Initial arc length (Larc)

The initial arc length influences the secondary arc extinction time. As time progress, the arc elongates from this initial length until it is finally extinguished. Since the exact value of the initial arc length is not a precisely known quantity, results are presented for 3 assumed values of Larc; 2 m, 4 m and 6 m.

### Magnitude of the primary arc (Ip)

This is the magnitude of the fundamental component of the single line to ground fault current at a specific fault location. This value can be calculated from fault studies or, in this case, through a PSCAD simulation itself. To calculate this value from the PSCAD circuit, the fault is assumed to be solid with zero arc resistance.



Figure The PSCAD arrangement to measure the primary and the secondary arc (fundamental component) current.

### Magnitude of the secondary arc (Is)

This is the magnitude of the fundamental component of the single line to ground fault current at a specific fault location after opening the two line end breakers. This value can be calculated from fault studies or, in this case, through a PSCAD simulation itself. To calculate this value from the PSCAD circuit, the fault is assumed to be solid with zero arc resistance. Once the two breakers are open, the phase coupling sustains the fault current.

In order to perform the secondary arc simulation studies, the Is and Ip values were estimated for three locations on the line (sending end, receiving end and mid-point).

# Simulation results

The extinction time and the recovery voltage should be tested under various system operating conditions.

For example:

1. Arc extinction time and recovery voltage for the line with all reactors in service
2. Arc extinction time and recovery voltage for the line with all reactors out of service
3. Arc extinction time and recovery voltage for the line with reactors on the ‘healthy’ circuit out of service

# References

1. E. W. Kimbark, "Suppression of Ground-Fault Arcs on Single-Pole Switched EHV Lines by Shunt Reactors," IEEE Transactions on Power Apparatus and Systems, vol PAS-83, pp. 285-290, March/April 1964.
2. E. W. Kimbark, "Selective-Pole Switching of Long Double-Circuit EHV Lines," IEEE Transactions on Power Apparatus and Systems, vol PAS-95, pp. 1, January/February, 1976.
3. IEEE Committee report, “Single phase tripping and auto reclosing on transmission lines”, IEEE Trans. On Power Delivery, vol 7, pp182-192, Jan, 1992.
4. M.R.D.Zadeh.; Majid Sanaye-Pasand.; Ali Kadivar.; “Investigation of Neutral Reactor Performance in Reducing Secondary Arc Current”, IEEE trans. Power Delivery, vol. 23, no. 4, Oct 2008.
5. Improved techniques for modelling fault arcs on faulted EHV transmission systems, A.T. Johns et.el. IEE Proceedings, Generation, Transmission and, Distribution, Vol. 141, No.2, March 1994.

# 

# Appendix 1 Calculation of the NGR – Method 01

The NGR is used to cancel the capacitive component of the secondary arc current [1]. In order to cancel the capacitive current, the inductive and capacitive branches must resonate. By satisfying this condition, the appropriate amount of neutral reactor is achieved, as calculated from equation (1) [2]. Installation of this reactor is effective when capacitive coupling becomes symmetrical through phase transposing.

(1)

Where:

B1: positive sequence line susceptance (Siemens in this case =0.00144S);

B0: zero sequence line susceptance (Siemens. in this case = 0.000838S);

: shunt compensation degree.

Xn: equivalent reactance of the NGR.

Xr: equivalent reactance of the line reactor.

Xn: equivalent reactance of the neutral grounding reactor (NGR).

In this case, as 80 MVAR reactors with 1800Ω reactance are installed at both ends of the transmission line, equivalent reactance of each of the line reactors cab be considered as 1800/2 = 900 Ω. Hence the compensation degree F = 1/(0.00144x900) = 77%. The appropriate neutral reactance is obtained as 360Ω using equation (1). This equivalent reactor can be realized using two neutral reactors installed at the neutral of both line end reactors, each having reactance of 2x360=720Ω or 1.91H.

# Appendix 2 Calculation of the NGR based on the Basic Impulse Insulation Levels (BIL)

Appendix 1 Calculation of the NGR – Method 01presented the calculation for the NGR. It is possible to select a NGR with higher or lower reactance due to simplicity in design, availability and cost. One concern for the selection of NGR is the Basic Impulse Insulation Levels (BIL). The minimum acceptable BIL for the neutral point can be calculated by [4]:

(2)

Where:

BIL\_N: Basic Impulse Insulation Level for the NGR.

BIL\_Ph: Basic Impulse Insulation Level of the phase.

For the 380kV system, BIL\_Ph = 1050 kV. Thus the BIL for the neutral point is 300 kV. Usually for the 380kV system, the BIL of the neutral point of the line reactor is less than 350 kV. Because the larger neutral BIL level requires special design and more insulation for the line reactor, the cost of the line reactor and neutral reactor increases. Hence in this case for the 1800Ω line reactor, the NGR reactance should be no larger than the value given by the following equation (if BIL\_N=350).

(3)