Electric Power Systems Research 138 (2016) 106–112

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Evaluation of relaying impedance algorithms for series-compensated line

Murari Mohan Saha[a], Eugeniusz Rosolowski[b], Jan Izykowski[b,*], Piotr Pierz[b]

[a] ABB AB, S-721 59 Västerås, Sweden
[b] Wroclaw University of Science and Technology, Wyspianskiego 27, 50-370 Wroclaw, Poland

ARTICLE INFO

Article history:
Received 15 December 2015
Received in revised form 18 March 2016
Accepted 29 March 2016
Available online 11 April 2016

Keywords:
Transmission line
Series capacitor compensation
Faults
Digital distance protection
Impedance algorithms
ATP-EMTP simulation

ABSTRACT

A group of the algorithms of fault-loop impedance determination for digital distance relay applied for protecting a series-compensated line has been considered. The algorithms gathered in two basic families have been tested: (i) the methods based upon Fourier orthogonal components with using both full-cycle and half-cycle data windows; (ii) four variants of the method founded on differential equation techniques, i.e. with applied various digital differentiation rules, with included additional pre-filtration and combined with orthogonal components determination. Extensive simulation studies have been performed for comparing the calculation techniques. Recommendations with respect to impedance algorithms suitable for protection of a series-compensated line have been stated. The other studied algorithm is related to fault direction discrimination for the considered series-compensated line arrangement. Sample simulation results have been presented and discussed.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

Increased transmittable power, improved power system stability, reduced transmission losses, improved voltage control and flexible power flow control are the primarily reasons behind installing series capacitors (SCs) on long power transmission lines. The installation costs usually do not exceed 15–30% of a new line and are not affected by the environmental concerns [1].

When a series-compensated line suffers a fault behind its SCs, as seen from the relaying point (Fig. 1 – the fault F_2 for the Relay A and the fault F_1 for the Relay B), a fault loop considered by a distance relay contains, depending on type of fault, one or even two complexes of SCs and their overvoltage protecting arresters (usually metal-oxide varistors (MOVs)). The presence of MOVs makes a fault loop strongly nonlinear and nature of transients of the relaying signals is entirely different than for traditional lines. This creates certain problems for its protective devices [2,3] and fault locators [4].

In case of the algorithms aimed at determining fault location for an inspection-repair purpose a speed is not important and thus complex calculations can be applied to satisfy the imposed requirements [5–7]. In turn, for the considered here distance protection of series-compensated line, a possibly high speed is expected to be achieved under transient conditions relevant for such lines. This calls for detailed investigation of both impedance measuring algorithms and auxiliary algorithms dedicated for fault detection, phase selection and direction detection.

This paper is focused on selecting a digital algorithm for fault-loop impedance measurement suitable for application to a series-compensated line distance protection. For this purpose the Fourier algorithms [11,12] were firstly investigated (Section 3). Then, in order to get improved operation, the differential equation based family of algorithms (Section 4) were taken into considerations. Apart analysing the basic forms of such algorithms [11,12] also it has been proposed to include additional pre-filtering or to combine the differential equation algorithm with orthogonal components [11,12] determination.

The other contribution of this paper relies on investigation of the algorithm for fault direction discrimination [8], also in an environment of the studied series-compensated line arrangement (Fig. 1).

The software package ATP-EMTP [9] was used as a simulation tool for generating fault data under versatile faults on the series-compensated line.

A single-circuit transmission line A–B (Fig. 1) is considered as compensated at 70% rate with a three-phase bank of series capacitors (SCs) installed in the middle.

* Corresponding author. Tel.: +48 71 3202658.
E-mail addresses: murari.saha@se.abb.com (M.M. Saha), eugeniusz.rosolowski@pwr.edu.pl (E. Rosolowski), jan.izykowski@pwr.edu.pl (J. Izykowski), piotr.pierz@pwr.edu.pl (P. Pierz).

http://dx.doi.org/10.1016/j.epsr.2016.03.046
0378-7796/© 2016 Elsevier B.V. All rights reserved.

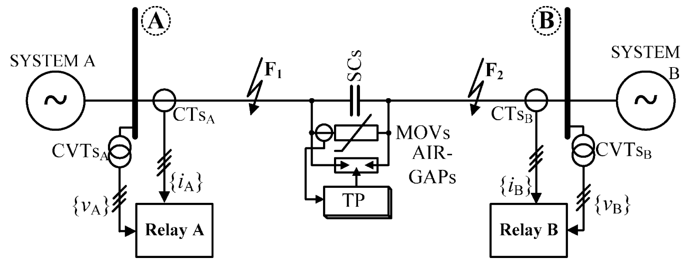

Fig. 1. Schematic diagram of the studied series-compensated system.

2. Model of series-compensated line

The 300 km, 400 kV, 50 Hz transmission line is modelled as a cascade of four-ports, each representing a 50 km long line segment (transposed Clarke model used) [9]. The line impedances for the positive- and zero-sequences were assumed in modelling as: $Z_{1L} = 0.315\,\Omega/\text{km}, 85^\circ$; $Z_{0L} = 1.0265\,\Omega/\text{km}, 75^\circ$.

The MOVs were modelled as non-linear resistors approximated by the standard v–i characteristic [10]:

$$i = P\left(\frac{v}{V_{REF}}\right)^q \tag{1}$$

where q, P, V_{REF} MOV parameters. The parameters of the approximation (1) for the characteristic assumed in this study (Fig. 2c), were: $q = 23$, $P = 1$ kA, $V_{REF} = 150$ kV.

Each MOV is protected from overheating by firing the complementary air-gap by the thermal (overload) protection (Fig. 2). The

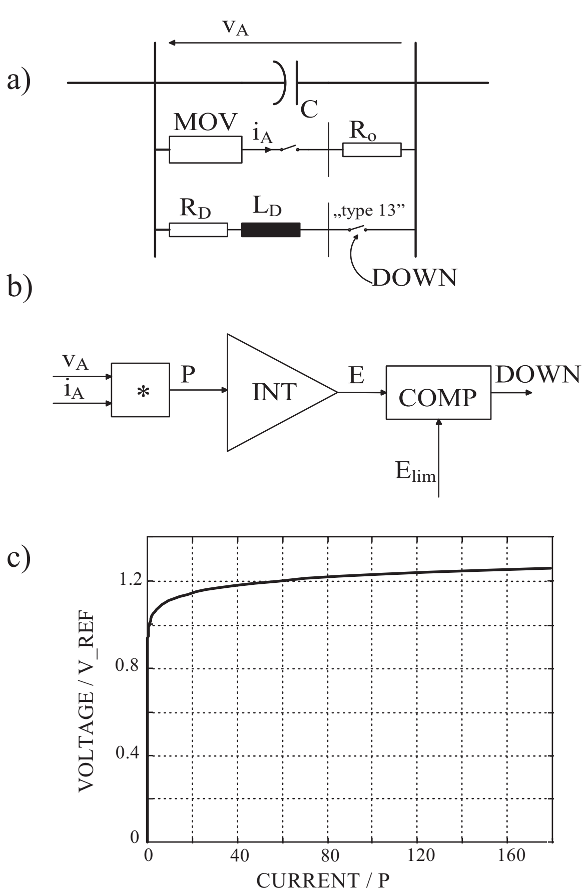

Fig. 2. Modelling of series capacitor equipped with MOV: (a) adopted scheme, (b) structure of algorithm for thermal protection of MOV, and (c) voltage-current characteristic of MOV.

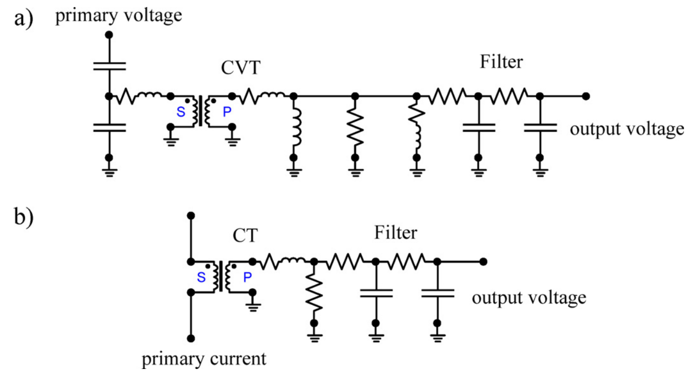

Fig. 3. Modelling of measurement chains of distance relay: (a) measurement of voltage and (b) measurement of current.

MOV protection was modelled as energy-based using ATP-EMTP MODELS: the energy absorbed by the MOV is integrated and the MOV becomes shunted by firing the air-gap (the signal DOWN causes closing of the type 13 switch) when this energy reaches its pre-defined limit.

The relay measuring chains were modelled as well (Fig. 3). Capacitive voltage transformers (CVTs) were represented by their 4th order linear models while current transformers (CTs) were simulated taking into account their saturation branches. The analogue anti-aliasing filters were represented by the 2nd order approximation (filters in Fig. 3a and b which are in the form of 4-port network consisting of double R–C circuits) with the cut-off frequency set at 1/3 of the sampling frequency f_s ($f_s = 1$ kHz was assumed in this study). The secondary current of CT was converted to voltage by taking the voltage drop across the CT load as the input to the anti-aliasing filter from where the output voltage was recorded for further processing (Fig. 3b).

Variety of conditions with respect to the supplying systems were considered – however, in all the tests of this paper the impedances of the local (A) and remote (B) sources were taken as identical and equal to: $Z_{s1} = Z_{s2} = 15\,\Omega, 85^\circ$, $Z_{s0} = 26.6\,\Omega, 85^\circ$. The remote sources (behind the bus B) were delayed by 10° with respect to the local sources (behind the bus A).

3. Fourier methods

Distance protection of a transmission line requires measurement of a fault loop impedance (R, X). Comparison of the measured impedance with the characteristics properly shaped on an impedance plan enables to make a decision whether a fault occurred in the protection zone or not. In order to provide adequately fast disconnection of a faulted line such a decision ought to be made very fast – basically within time shorter than a fundamental frequency cycle for modern relays.

The aim of this study is to develop the measuring algorithm for fast operating relays applied for protection of series-compensated lines. First, the Fourier filters [11,12] have been taken into consideration. According to them impedance components (R, X) of a fault loop are estimated with the orthogonal components [11,12] of voltage and current from a fault-loop:

$$R = \frac{u_c i_c + u_s i_s}{i_c^2 + i_s^2}$$
$$X = \frac{u_s i_c - u_c i_s}{i_c^2 + i_s^2} \tag{2}$$

where u_c, i_c, u_s, i_s – direct (cosine) and quadratic (sine) orthogonal components of voltage and current, respectively.

Download English Version:

https://daneshyari.com/en/article/704393

Download Persian Version:

https://daneshyari.com/article/704393

Daneshyari.com