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REAL EFFICIENCY OF INTELLIGENT SWITCHING OF HIGH VOLTAGE CIRCUIT-BREAKERS

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The concept of intelligent switching means extending the existing controlled switching characteristics to new situations from which the case of faults is the most important. One of the main aspect is related to modern high speed circuit-breakers which are opening before the d.c. component of the short-circuit current is closed to zero. Based on authors' main research results in implementation of intelligent switching of high voltage circuit-breakers in case of faults, the paper deals with the real advantages and efficiency of this relative new technology in power systems. Between main positive results of this new technology there is a major power quality improvement as much as the overvoltages and overloads are strongly diminished.

Keywords: intelligent switching, stress mitigation, circuit-breakers

1. Introduction

"Controlled switching" is one of several terminologies applied to the principle of coordinating the instant of opening or closing of a circuit with a specific target point on an associated voltage or current waveform. Other common terminologies applied include "synchronized switching", "point-on-wave switching".

This technology was progressively developed, during last decades, not only from theoretical aspects [1], [2], state-of-art statistical reviews [3], but also from practical applications [4], [5].

All, or most of the electronic devices allowing for controlled switching are especially recommended for normal steady-state, or so-called conventional, switching and not in case of faults as table 1 shows according to [3].

2. Models and techniques for intelligent switching in case of faults

2.1 Pötl and Fröhlich method based on 'safe points'

The most recent published method for synchronized fault interruption found was an approach developed by Pöltl and Fröhlich, in 2003 [2]. This approach proposed a novel scheme whereby the synchronization target is not directly based on a future current zero, but rather on a chosen periodically occurring instant on the fault current, known to always precede a current zero,

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referred to as a “safe point”. The authors proposed a set of different safe points for different switching cases; symmetrical, shifted and asymmetrical fault currents. These are illustrated in fig. 1 and fig. 2.

Table 1

Results of worldwide survey of controlled switching applications installed between 1984-2001 [3]

Controlled component and switching type	Percent form the total of 2500 applications
Energising / de-energising of shunt capacitors	64%
Energising / de-energising of shunt reactors	17%
Energising / de-energising of power transformers	17%
Energising / de-energising of lines	2%
Combined controlled opening and closing of three-pole operated mechanically staggered circuit-breakers	7%

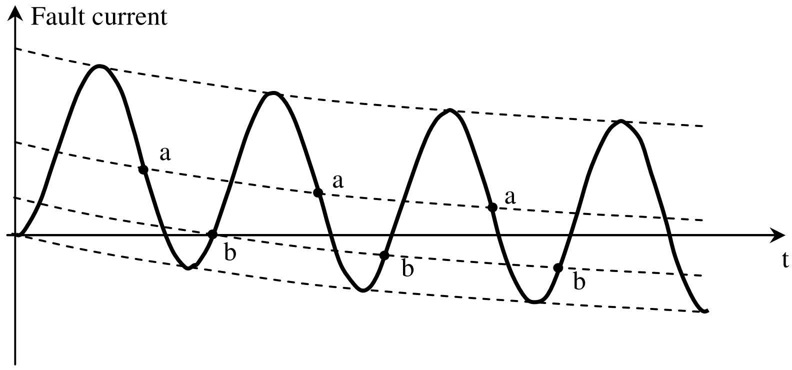


Fig.1 Controlled switching method, in case of an infinite power source, based on ‘safe points’:
a) symmetrical; b) shifted [7]

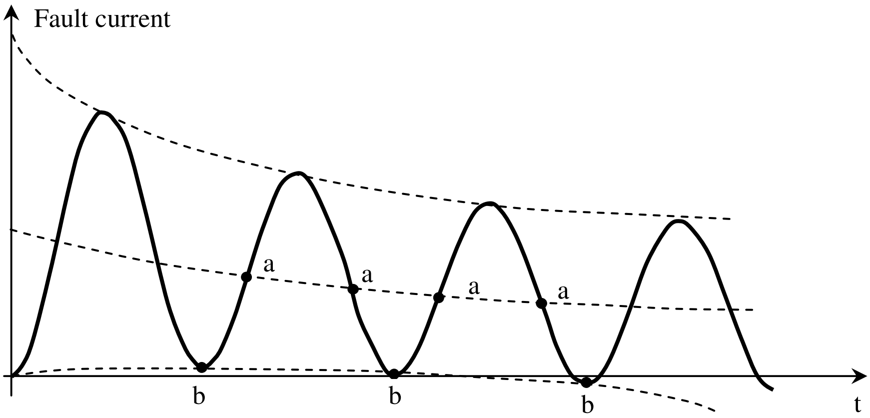


Fig.2 Controlled switching method, in case of a finite power source, based on symmetrical (a) and asymmetrical (b) ‘safe points’ [2]

2.2 Richard Thomas method based on LMS algorithms

As opposed to the “safe point” approach, the scheme proposed by Richard Thomas [6] is based on predicting future current zero behavior and synchronizing the tripping command to the circuit breaker with respect to the earliest viable, predicted current zero(s) accordingly. Contrary to the “ideal” circuit breaker with near zero arcing time implied by the concepts mentioned by Gerszonowicz and Garzon, the author has focused on potential application to existing modern SF_6 circuit breaker designs, for which certain minimum arcing time behavior has been, or could be, established from conventional type testing.

The proposed controlled switching algorithm is based on determination of the characteristic parameters of the instantaneous single-phase fault current model described by equation:

$$i_f(t) = I_F[\sin(\omega t + \alpha - \varphi) - \sin(\alpha - \varphi)]e^{-t/\tau} + I_{PF\alpha}e^{-t/\tau} \qquad (1)$$

where,

t = time;

I_F = peak steady state fault current magnitude;

$I_{PF\alpha}$ = the instantaneous pre-fault current magnitude at fault initiation;

ω = power system angular frequency;

α = fault initiation angle with respect to driving source single-phase voltage;

tan (φ) = ωL/R; L = source-to-fault series inductance and R = source-to-fault series resistance;

τ = L/R = time constant of the exponentially decaying asymmetrical component(s).

The key unknown parameters to be determined in equation include I_F, α, φ and τ. It is clear that φ and τ are related through L, R and ω. For the short time transient durations that the parameters must be calculated it is assumed that the power system frequency is constant.

Various methods could be applied to try and ascertain the unknown characteristic parameters. Some investigation was made of the possible use of discrete derivatives of the sampled current in order to predict future zero crossing behavior, but such methods are inherently noise sensitive. What has been selected and examined in most detail in Thomas’ paper has been a method based on least mean square regression analysis.

Advantages of LMS methods include:

- flexibility to data window sizes;
- tolerance to noise;
- relatively straightforward mathematics.

Potential disadvantages of LMS methods include:

- processing burden proportional to square of data window size;
- assumption of linearity in the data - (strictly this is a non-linear regression problem);
- viability of the chosen regression model with respect to range of possible fault behaviors;
- management of exponential terms.

2.3 This paper authors' method based on fault type detection and normalisation of the d.c. component of fault current

The authors of the present papers elaborated a new method to anticipate the first zero crossing of fault current. Essentially it is based on a qualitative (without any calculation due to extremely necessary speed of type of fault detection) evaluation of the initial values of d.c. components (I_{dca}, I_{dcb}, I_{dcc}) [7]. The result is a hybrid relay shwon in fig.3.

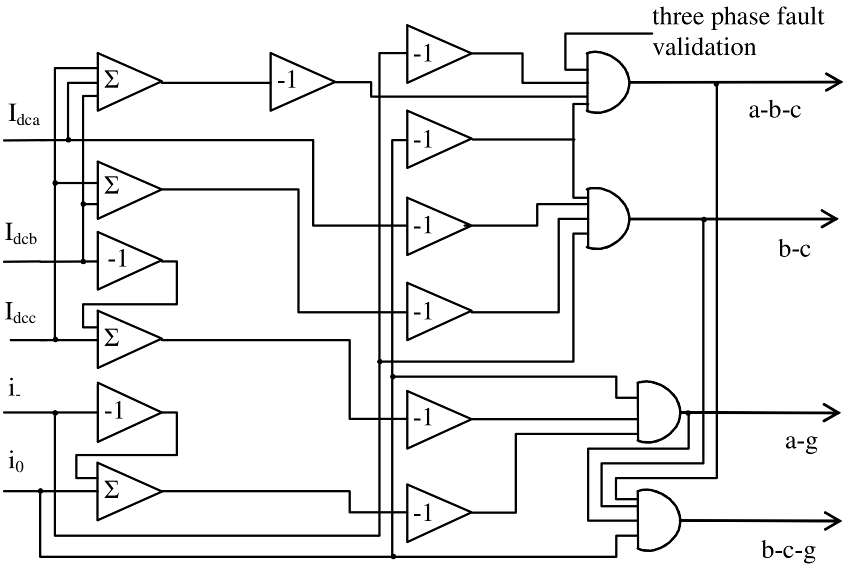


Fig.3 The principle of a hybrid structured relay for fault type detection

After this, it is easier to anticipate the first zero crossing and even it will be the case of a zero crossing missing.

The relation describing the fault current on phase a, in the simplified case of an infinite power source case, is given by:

$$i_{ka} = I_F \sin(\omega t + \alpha - \varphi) + [I_{PF\alpha} \sin(\alpha - \varphi) - I_F \sin(\alpha - \varphi_k)]e^{-\frac{t}{\tau}} \qquad (2)$$

where the notations are the same like in eq. (1) excepting the pre-fault power factor φ.

The most important observation is related to this variable, φ *which was not included in the eq. (1) for a correct analysis.*

One of the most important problems related to the fault current first zero crossing anticipation is to evaluate the number of measurements on the total fault current wave to optimize the duration – accuracy ratio and, consequently, to be in time with switching command.

The author's studies [8] conducted to the correct answer and conclusions. According to the notations in fig 4, the key elements of the method to solve the above mentioned problems are:

- Δtd, time interval for mechanical breaker opening;
- tn, necessary time interval for data acquisition related to the c.c. fault component with a view to accurately anticipate his evolution for intelligent switch;
- tr, real time estimated for the fault current first zero crossing on that phase.

Zero time is the fault initiation moment.

According to fig.4, the restriction for intelligent breaker switching, neglecting the time for fault initiation detection is:

$$tn + \Delta td \leq tr \tag{3}$$

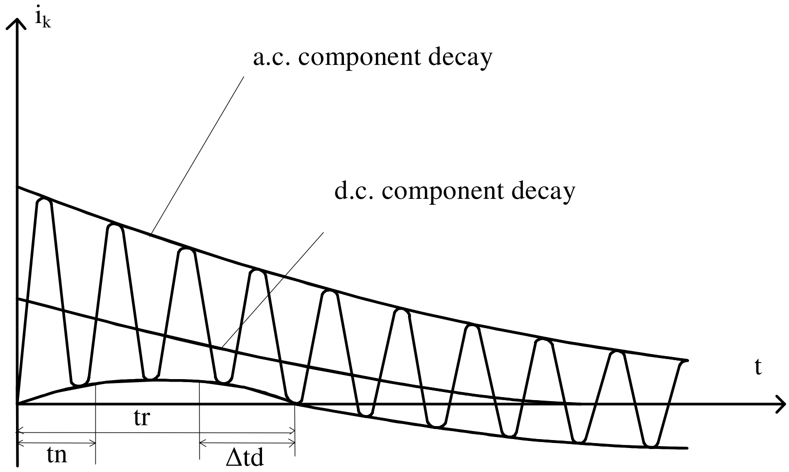


Fig. 3 The key elements to accurately anticipate the first zero crossing in the case of the intelligent fault interruption

Considering the possible necessary time interval for fault initiation detection, equation (3) becomes:

$$ti + tn + \Delta td \le tr$$

Continuous fault current component evolution anticipation and the time of the first time zero crossing of the total fault current are based on the calculation of the parameters of the d.c. component, given by

$$i_a = a \cdot e^{kt}; k < 0 \tag{4}$$

The normal equations system to calculate a and **k** parameters, is:

$$\begin{cases} \sum_{i=1}^{n} \log i_{ai} = 0.4343 \sum_{i=1}^{n} t_i \\ \sum_{i=1}^{n} t_i \log i_{ai} = 0.4343 \sum_{i=1}^{n} t_i^2 + (\sum_{i=1}^{n} t_i) \log a \end{cases} \tag{5}$$

Solving equation (5) can be done in an accurate and rapid manner so, the minimum measurements number (n) for a sufficient given accuracy has to be established to calculate **a** and **k** [9].

3. The real efficiency of the intelligent switching

The general benefits of controlled switching are related not only to the involved circuit-breaker but also to the network components and to the quality of delivered energy.

Limitation of transients is one of the most important benefits of controlled switching as presented in table 2.

Table 2

Techniques for switching transients mitigation

Method	Benefits	Desavantages
Constant inductace	Easy to install and use Current limitation	Energy losses and noisy Expensive
Resistance preinsertion	Short time insertion before switching No losses	Relative complicate Low reliability
Inductance preinserţion	Short time insertion before switching No losses Better solution compared to constant inductance	Technically complicated Low reliability
Synchronous circuit-breaker	Effective transients mitigation during opening and closing Reduced circuit-breaker wearing	-

The specific benefits are related to the switched component.

A typical example is the *shunt capacitor* for which the details are included in table 3.

Table 3

The benefits for controlled switching of shunt capacitor banks

Application	**Closing**	**Opening**
Optimal transient limitation	|U|: 2.0 p.u. |I|: minimal inrush current	|U|: better than rated circuit-breaker restrike probability
Other potential benefits	Longer breaker life	Longer breaker life
Optimal control targeting principles	Zero-voltage across breaker	1/4 - 1/3 cycle arcing time

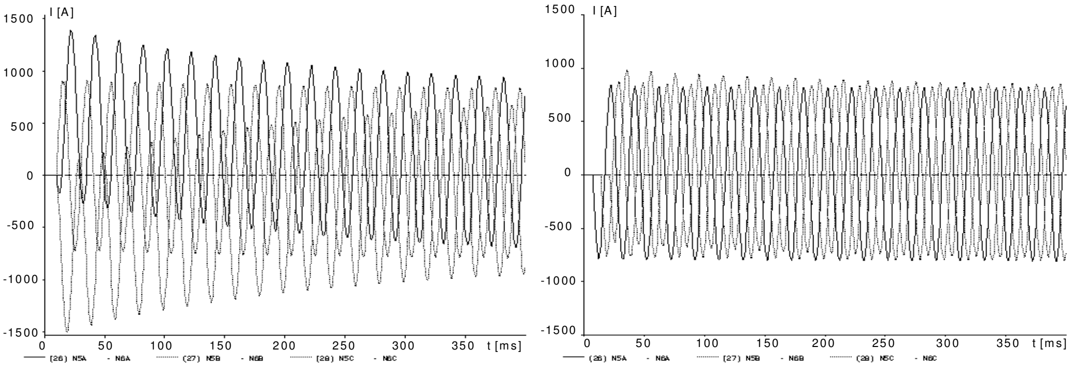
For shunt reactor banks, the similar advantages are presented in table 4.

Table 4

The benefits for controlled switching of shunt reactor banks

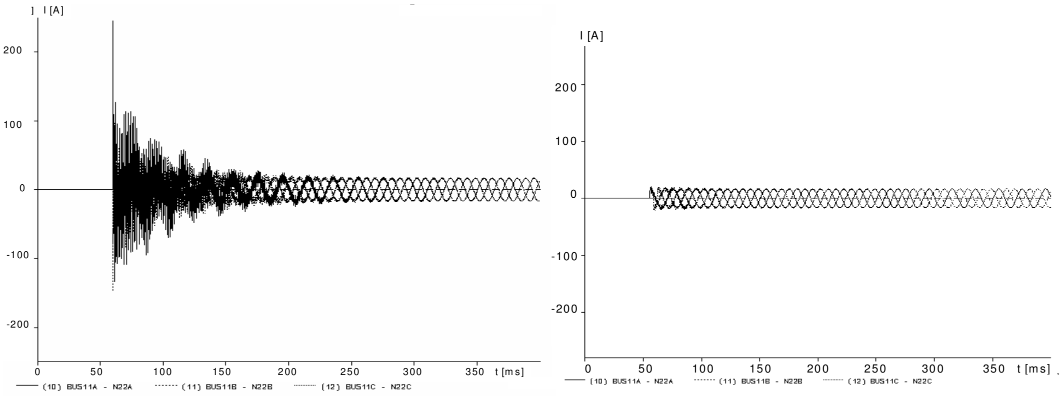
Application	**Closing**	**Opening**
Optimal transient limitation	|U|: 1.2 p.u. |I|: minimal dc inrush current	|U|: avoid reignitions Minimise chopping overvoltages
Other potential benefits	Longer breaker life	Longer breaker life Reduced stress of reactor insulation
Optimal control targeting principles	According to reactor configuration	1/4 - 1/3 cycle arcing time

The primary focus for controlled switching of *power transformers* is normally on energization control in order to minimize current inrush transients and their effects. The similar purpose is in the case of power lines energization. Figures 4 and 5 shows clearly these real effects [8].



a) b)

Fig. 4 Phase inrush currents during the energization of 400/220 kV, 400 MWA power transformer: normal switching, worst case (a) and controlled switching (b)



a) b)

Fig.5 Phase currents during the energezation of a 220 kV power line: normal switching, worst case (a) and controlled switching (b)

4. Conclusions

This paper focuses on the methods' principles of controlled switching. The authors' method was implemented in a high voltage power station for controlling a 220 kV transmission line in case of faults inclusive.

According to the type of switch (opening or closing) and the type of component (capacitor bank, reactor bank, power transformer, power line, etc.) the real advantages of intelligent controlled switching are a very effective control of switching surges for different applications, a better power quality, and reduced stress of power system components, lower maintenance costs for circuit-breakers.

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