Indian Journal of Science and Technology Vol. 5 No. 7 (July 2012) ISSN: 0974- 6846

Simulation and solving the descriptive equations on the voltage breakdown in ultra-quick circuit breakers

Adel Moradi[1*], Bahram Noshad[1*] and Mohammad Sadegh Javadi[2]

[1*]*Department of Electrical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran*
[1]*Department of Electrical Engineering, Mahshahr Branch, Islamic Azad University, Mahshahr, Iran*
[2]*Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Fars, Iran,*
morady11@yahoo.com, BahramNoshad@yahoo.com, msjavadi@gmail.com

Abstract

This paper presents descriptive equations on the voltage breakdown in ultra-quick circuit breakers (UQCB). In this paper, main breakdown characteristics of UQCB's are presented. Gaseous breakdown in the sub-nanosecond regime is of interest for fast pulsed power switching, short pulse electromagnetics, and for plasma limiters to protect devices from high power microwave radiation. In order to study pulsed gas breakdown initiation dynamics, a sub-nanosecond voltage pulse is simulated by Electro-Magnetic Transient Program (EMTP).

Keywords: Ultra Quick circuit breakers, Voltage breakdown, Gaseous breakdown, Transient recovery voltage.

Introduction

Newer developments in the field of high speed/high power electromagnetics applications, such as Ultra-wideband (UWB) radar, plasma limiters, and fast general purpose pulsed power applications, require high power switching times far below one nanosecond. Information about switch closure times and standoff voltages for short pulses is of relevance for many switching and insulation tasks, for volume breakdown in different media as well as for surface discharges along interfaces.

The physics background for breakdown caused by short pulses with high over-voltages is far from being clear. Some publications from the 1960's on delay times include the work of (Felsenthal & Proud, 1965). Physical models discussing streamer development under electron runaway conditions have been introduced by Kunhardt and Byszewski (Kunhardt & Byszewski, 1980; Kunhardt *et al.*, 1986; Kunhardt & Tzeng, 1988), and experimental data on the development of breakdown current and x-ray emission due to fast electrons in nanosecond pulses of several 10-kV amplitude have been given by Byszewski (Byszewski *et al.*, 1982; Byszewski & Reinhold,1982). More recent work originated prevalently from Russia, and emphasizes the role of runaway electrons for discharges in relatively low pressure gases (2005; Babich, 2003; Kostyrya *et al.*, 2004; Tarasenko & Yakovlenko,).

The first results of the studies of fast electric-discharge processes accompanying pulsed nanosecond gas breakdowns were published by (Fletcher, 1949). Subsequent numerous studies were devoted to investigations of the nanosecond gas breakdown at pressures of several to tens of atmospheres. Many experiments have shown that the processes initiating the production of initial electrons on the electrodes' surfaces and inside the volume of the gas-discharge gap determine to a great extent the breakdown development character.

When pre-breakdown over voltage times shorter than 1 ns are used, the initiation stage becomes comparable with the development time of the breakdown itself. Here, the nature of the initiation mechanism changes, which is associated with a rise in the degree of the gap over-voltage attained in comparison to a static breakdown. The transition dynamics of the field emission from the cathode electrode surface to the explosive electron emission begins to play an important role (Nasser, 1971; Park *et al.,* 2007).

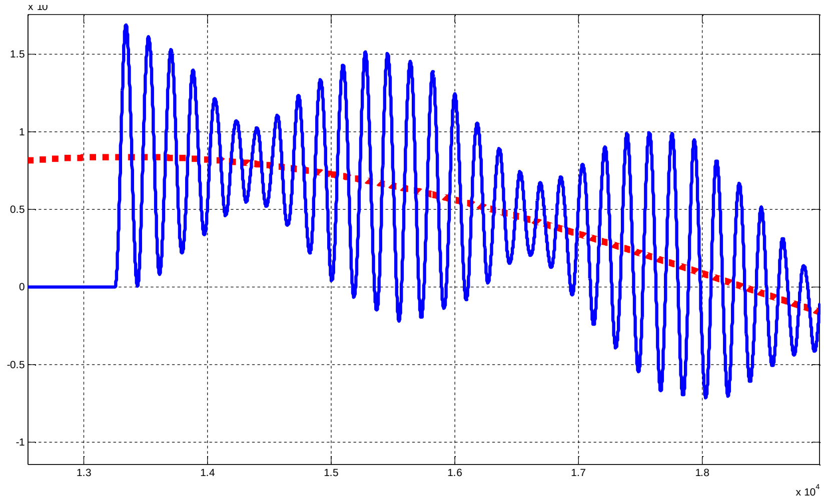
Fresh opportunities open up in the study of processes of initiation and development of a sub-nanosecond gas breakdown if the experiment ensures stable characteristics and continuously controllable parameters of the high-voltage sub-nanosecond pulses applied to the gap under study: the amplitude, duration, and voltage rise rate at the leading edge. Another factor that determines the possibility of detailed studies of the breakdown dynamics characteristics is the high-precision synchronization of the measuring facilities recording the processes in real time to within the necessary relative and absolute locking accuracy.

Gaseous breakdown

In order for breakdown to occur between two electrodes, at least one electron must be emitted by the cathode or be otherwise introduced into the gap. The production of electrons from a surface can be due to six primary mechanisms: chemical or nuclear processes, field emission, electron impact, positive ion bombardment, radiation (photoemission), and thermionic emission (Khodabakhchian, 2006). Although there is constant ionization as a result of cosmic radiation, creating a density of about 10 cm" positive and negative ions, the lifetime of free electrons and positive ions is rather short (Khodabakhchian, 2006). Taking into account the short lifetime and relatively low density of these "background" electrons, they are not considered as a major contributing factor to the development of breakdown in this experiment. Since this experiment uses no form of deliberate external ionization to induce breakdown, this discussion will focus on the initial electrons being emitted from the cathode surfaces as a result of the applied pulse.

Indian Journal of Science and Technology Vol. 5 No. 7 (July 2012) ISSN: 0974- 6846

*Fig. 1.*Power frequency (dot) versus the TRV oscillations frequency *(solid)*



Initial electron emission mechanisms

In examining the source of the initial electron emission leading to breakdown, several of the possible mechanisms can be eliminated either by the nature of the experiment or by the conditions present in the experiment prior to any discharge. The possible processes that remain are thermionic emission and field emission, as well as electron turmeling. Of these, field emission will be emphasized because this experiment deals with the application of a strong electric field (150 kV/cm) to the gap under test.

However, because electron tunneling is the dominant mechanism at low temperature (< 300K) and thermionic emission is fundamentally related to field emission, all mechanisms will be discussed.

Thermionic emission

Thermionic emission can be defined as the liberation of electrons from a metal electrode into its surroundings without the influence of any outside fields. This kind of emission can occur at any temperature and takes place when electrons become thermally excited and attain sufficient energy to jump the potential barrier. Applying an external field can modify the energy necessary to overcome the barrier, but this falls into the category of field emission and will be covered in the following section. At typical ambient temperatures, ~300K, thermionic emission is considered negligible; however, the emission increases exponentially as temperature rises. This is illustrated by Richardson's equation for the saturation current density (Khodabakhchian, 2006).

Field emission

Applying a strong external field can modify the energy necessary for an electronto leave a metal surface. This applied field serves to effectively reduce the potential energy barrier to the point that electrons with energy insufficient for thermionic emission at ambient temperature can escape. In essence, field emission is thermionic emission occurring at artificially low temperatures. An electron that passes over or tunnels through the barrier will experience a certain amount of force that will define how much initial energy that electron has.

Electron tunneling

In discussing thermoionic and field emission, the electrons attained sufficient energy to jump the potential barrier. Electron tunneling, or the tunnel effect, allows electrons with insufficient energy to jump the potential barrier created by the applied field, to turmel through it. Electron tunneling is examined statistically, with the probability of an electron successfully turmeling through the barrier exponentially dependent on the turmeling distance. Because the tunneling distance is inversely proportional to the applied field, the function for electron density should be an exponential function of the reciprocal of the field (Khodabakhchian, 2006).

As the applied field becomes more intense, the tunneling distance decreases causing emission by the tunnel effect to increase. The energy levels seen in tunneling electrons and emitted electrons are fundamentally different. Electrons that are emitted by

Fig. 2. CB curves for 121kV voltage levels and above

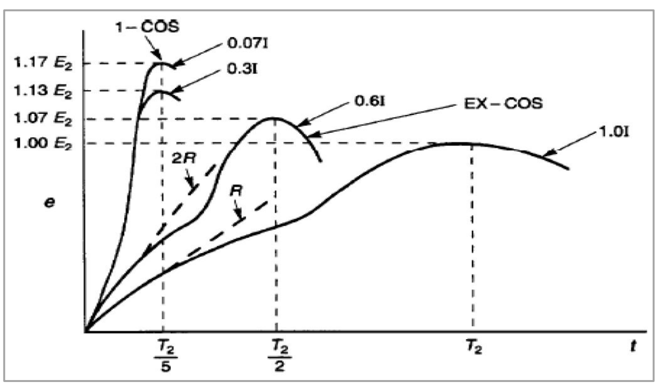


Fig. 3. TRV envelope curve

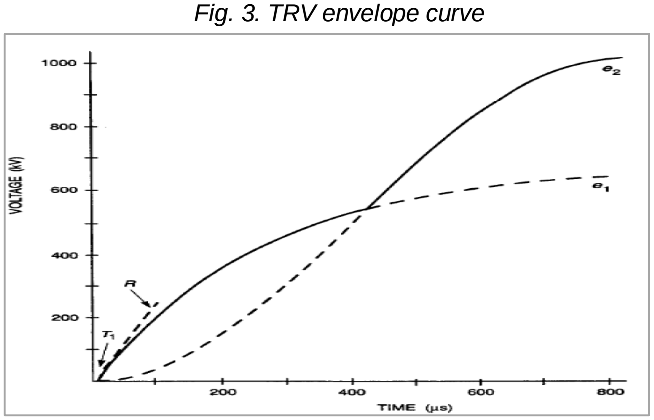


Fig. 4. Typical test system

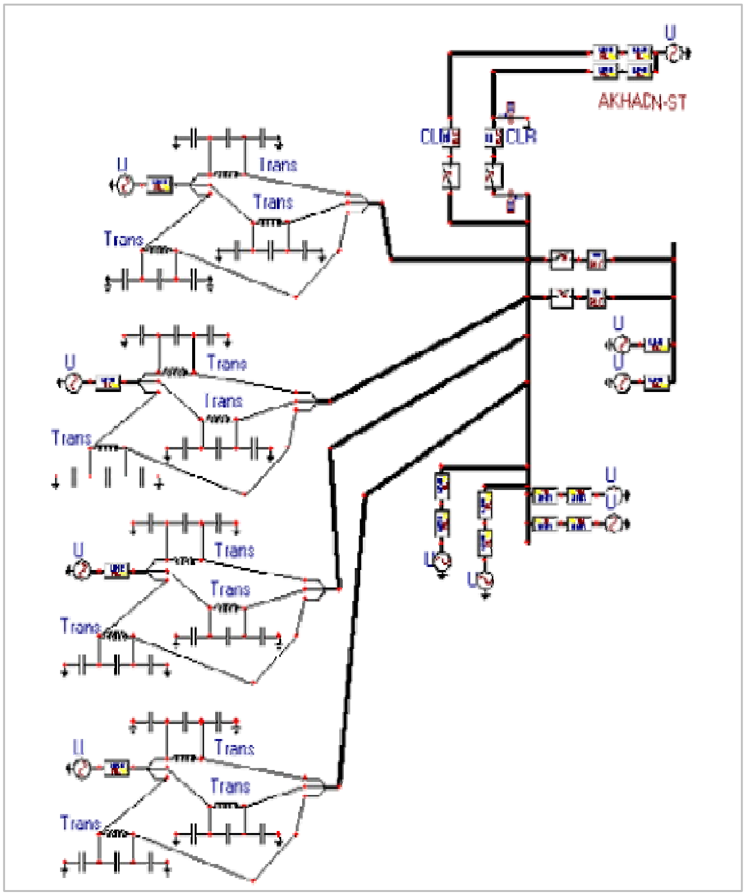


Fig. 5. TRV envelope curve per phase representation (Successful)

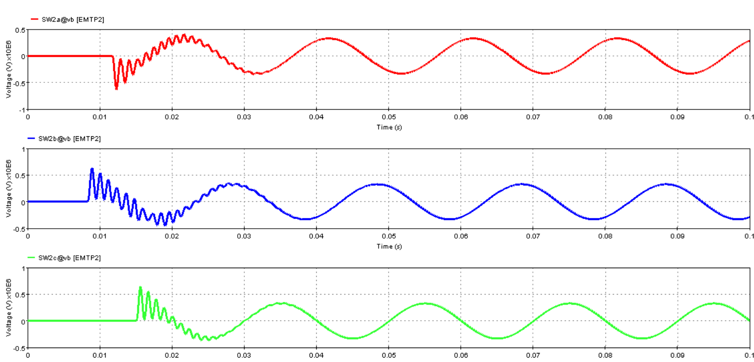
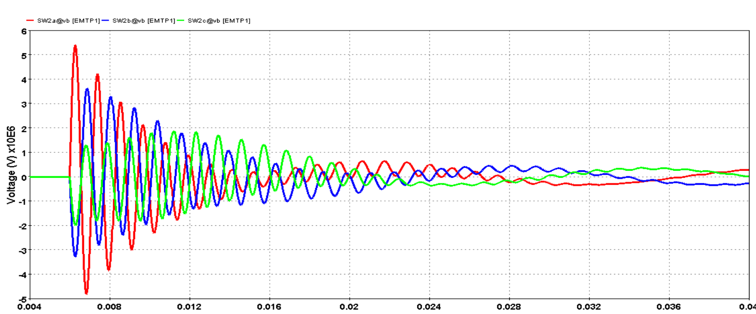


Fig. 6. TRV envelope curve (Unsuccessful)



thermionic processes experience a Maxwellian energy distribution, while electrons that turmel through the barrier escape with almost no energy (Khodabakhchian, 2006).

These instructions give you the guidelines for preparing papers for International Review on Modelling and Simulations. Use this document as a template if you are using Microsoft Word 6.0 or later. Otherwise, use this document as an instruction set. The electronic file of your paper will be formatted further at the International Review on Modelling and Simulations. Define all symbols used in the abstract. Do not delete the blank line immediately above the abstract; it sets the column format.

Circuit breaker requirements

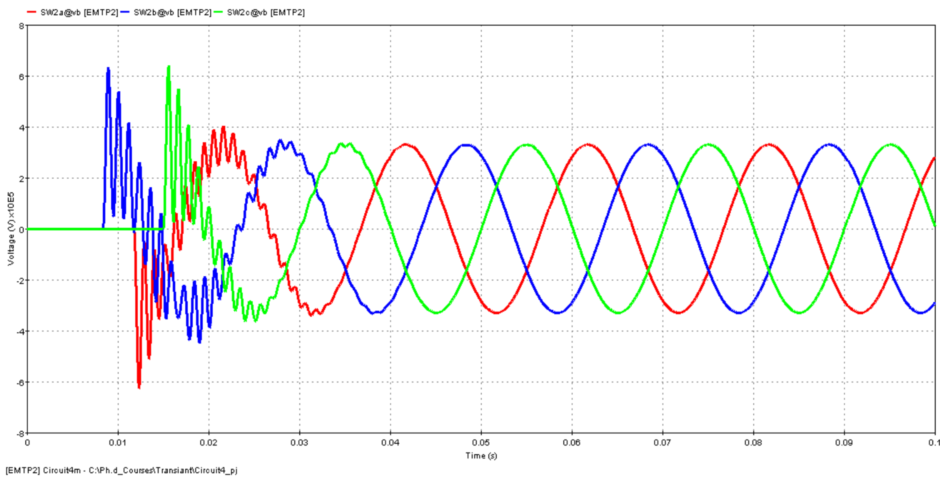
Any change in the network requires a comprehensive study of Technical and economics. Due to the continuing importance of energy and the influence of any change in the power network, the power system is very conservative to any changes in the topology of power network. So, the power system is always is opposed to any change in the existing arrangement in the power network. However, this issue may cause some terrible events in the power system (Porkar & Abedi, 2009).

Although different standards for such conditions are presented, but the offered suggestions for each network may not be acceptable for all cases. Thus, for using the advantages of these proposals, the over size design also is carried out. Several incidents of explosion of CBs in power transmission networks and sub-transmission have been reported in Iran (Porkar & Abedi, 2009). The most usual reason of these explosions has been the disability of the CBs in the extinction of the fault current-generally due to network topology changes and increased levels of short circuits of the main power stations or the adjacent power stations.

IEEE C.37 standard evaluates the capability of the CBs for fault current extinction on the base of the $1-\cos\omega t$ envelope curve. Accordingly, it is possible to determine statically for how much fault current the CB has the interruption capability and in what conditions it may not have a desirable operation.

Regarding the supplementary equipments for each CB such as reactors and capacitors, any CB has implicitly a Transient Recovery Voltage (TRV) interruption capability curve. The, $\omega = 2\pi f$ frequency in the $1-\cos\omega t$ envelope curve is determined by this standard for each CB and for every conditions. In this Standard, the conditions have been considered as static. This means that the power frequency has been disregarded against the TRV oscillation frequency. For example, the Fig.1 shows the differences between the power frequency and the TRV oscillations frequency.

Fig. 7. TRV envelope curve (Marginally Stable)



The investigation showed that TRV control measures needed to be taken. Details of these control measures, including the development of dedicated capacitive equipments to apply across the series reactor, are described.

The purpose of series reactors is to limit the magnitude of fault current. The reactors can be applied in a number of locations in order to achieve this purpose, on main buses, on feeders or in transformer neutrals.

The following are the specific objectives of this paper on transient recovery voltage requirements associated with the application of current-limiting series reactors:

1. Determine the TRV requirements associated with protective line circuit breakers for representative switching stations for the system under study for faults located just beyond the series reactor on the line-side.
2. Specify the capacitance needed, and placement of capacitance, to control the TRV to within acceptable limits, as necessary, from the frequency response point of view.

TRV Curve extraction for circuit breaker

According to the standard (IEEE Std. C37.011-1994), TRV CB curves for 121kV voltage levels and above is as following:

Regarding Fig.2, the TRV envelope curve for the nominal fault current is an exponential-cosine curve. In this Figure, in addition to the TRV envelope curve for the nominal fault current, the TRV curves for 60%, 30% and 70% of the nominal fault current have been shown. According to this Figure, for 30% of the nominal fault current and lower, the curve has been turned from the exponential-cosine form to the exponential form. Considering the above explanations, the TRV envelope curve will be an exponential form (Fig.3).

According to this standard and the nominal fault current, the mathematical equation describing the exponential curve is as follows:

$$e_1 = E_1(1-\varepsilon^{-t/T}) \qquad (1)$$

$$e_2 = \frac{E_2}{2}(1-\cos(\frac{\pi t}{2}))$$

The CBs for rated 132 KV voltage should be able to tolerate the rated over voltages as (139 = 132 * 1.05) kV. So due to the standard, a 145 kV is selected.

Based on the (ANSI C.37.06-1987) for rated current and maximum voltage (E_{max}=145kV):

$$E_2 = 1.76E_{max} = 1.76*145 = 255$$

and:

$$T = 310\mu s \quad (4)$$

Typical test system and TRV envelope cures are presented in Fig.4,5,6,7.

Concluding remarks

This paper presents descriptive equations on the voltage breakdown in ultra-quick circuit breakers (UQCB). Based on the presented methodology, the system planner would simulate the system and determine the TRV requirement before incorporating new assets and analyze the system efficiency in confronting faults.

Acknowledgements

This work was extracted from research entitled by "Simulation and Solving the Descriptive Equations on the Voltage Breakdown in Ultra Quick Circuit Breakers" which is granted and supported by the Mahshahr Branch, Islamic Azad University, Mahshahr, Iran

References

1. *ANSI C3706*-(2000) AC high-voltage circuit breakers rated on symmetrical current basis-preferred ratings and related required capabilities.
2. Babich LP (2003) High-energy phenomena in electric discharges in dense gases. *ISTC Sci. & Technol. Series*. Arlington, VA: Futurepast, Inc.Vol. 2.
3. Byszewski WW and Reinhold G (1982) X-ray diagnostics of runaway electrons in fast gas discharges.*Phys. Rev*. A26, 2826-2831.
4. Byszewski WW, Enright MJ and Proud JM (1982) Transient development of nanosecond gas discharges.*IEEE Trans. Plasma Sci.* PS-10, 281-285.
5. Felsenthal P and Proud JM (1965) Nanosecond-pulse breakdown in gases. *Phys. Rev.* A139, 1797-1804.
6. *IEEE Std* C37.011 (1994) IEEE application guide for transient recovery voltage for ac high-voltage circuit breakers rated on a symmetrical current basis
7. Khodabakhchian B (2006) Potential risk of failures in switching EHV shunts reactors in a one-and-a-half breaker scheme. *Elect. Power Sys. Res.* 76, 655-662.
8. Kostyrya ID, Akakun VS, Tarasenko VF, TkachevAN and Yakovlenko SI (2004) The role of fast electrons in the formation of a pulsed volume discharge at elevated gas pressures.*Technical Phys. Letters.* 30(5), 411-414.

9. Kunhardt EE and Byszewski WW(1980)Development of overvoltage breakdown in high gas pressure.*Phys. Rev.* A21, 2069-2077.
10. Kunhardt EE and Tzeng Y(1988) Development of an electron avalanche and its transition to streamers.*Phys. Rev*. A38, 1410-1421.
11. Kunhardt EE, Tzeng Y andBoeuf JP (1986) Stochastic development of an electron avalanche.*Phys. Rev.*A34, 440-449.
12. Nasser E (1971) Fundamentals of gaseous ionization and plasma electronics. NY: Wiley-Interscience.
13. Park HS, Woo JW, Kang JW, HanKS and SO Han (2007) Analyzing TRV of CB when installing current limit reactors in UHV power system.*Proc.Int. Conf. Power Sys.Transients*, Lyon, France.
14. Porkar B and Abedi A (2009) TRV requirements associated with the application of current-limiting series reactors-Simulation and Evaluation.*Proc. Power Sys. Conf. PSC 24th*. Iran, 2009 (in Persian).
15. Tarasenko VF and Yakovlenko SI (2005) High power subnanosecond beams of runaway electrons generated in dense gases.*Physica Scripta*. 72, 41-67.