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Review

Aspects of arc-flash protection and prediction

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ABSTRACT

This paper provides a technological review of arc-flash protection of air insulated switchgear. It covers the whole range starting from switchgear design aspects until ultra-fast arc elimination. Special attention is paid to proactive technologies enabling preemptive detection of slowly developing faults. Various arc faults indicating phenomena are examined, and several sensor technologies for online monitoring are evaluated. Because preventive or predictive measures cannot totally eliminate the risk of arc faults, reactive protection by fast operating protection is justified. Two major reactive protection approaches are discussed: the current-limiting approach and the arcing time based approach. The benefits of protection based on simultaneous detection of light and overcurrent are explained. Finally the paper discusses arc elimination technologies and evaluates the concerns related to short-circuit devices.

Contents

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1. Introduction

Internal high power arc fault in switchgear is a reasonably rare incident, but can have very serious consequences unless the arc is rapidly extinguished. An arc fault causes hazardous impacts: thermal impact, pressure wave, flying particles, electrical and toxic impact. In addition to the hazard to personnel, substantial economic losses due to equipment damage and long system interruptions are common consequences.

There are a number of options to limit the risks related to arc faults. Some of the approaches emphasize arc prevention while others focus on technologies for arc mitigation. This paper gives an extensive overview of the whole field. Emerging technologies in arc fault prevention and very fast reacting protection systems are discussed more in detail.

2. A holistic view of existing arc-flash protection technology

Various approaches aiming at prevention or mitigation of arc flash incidents have been presented. There are significant differences in the methodology, based on traditions and cultural difference. Standardization is only partially a reason for different practices. For example in Europe, in spite of the influence of IEC standards, there is no universal practice to deal with arc flash issues.

Arc-flash protection methods can be categorized into many ways. Examples of categorization are division into passive and active methods, and division into proactive and reactive methods. Passive methods do not have any active component. Active methods include measurements and either reactive response (after arc-flash has been detected) or proactive response (pre-arc action when indication of a developing fault has been detected).

Approaches aiming at prevention of arc-flash, like design of switchgear, education of personnel, and maintenance practices, can be categorized into pre-ignition methods and passive methods. Fig. 1 presents the categorization and a holistic view of arc-flash protection.

In the following sections, the elements of the holistic view are examined in more detail. Special attention is paid to emerging technologies of arc prediction, i.e. online monitoring in order to detect developing fault before they escalate into high power arc faults.

However, there are faults which cannot be predicted by online monitoring, e.g. faults caused by direct human interaction or by animals, or faults caused by incorrect operation of switching devices. Therefore, reactive arc-flash protection, operating after arc ignition, is often considered justified. Along with online monitoring technologies, efficient arc mitigation technologies are reported in detail.

3. Arc-flash prevention

3.1. Education

Either direct or indirect human action is a common cause of arc faults. Education of workers, safety culture and rules regarding operation in an environment with possible arc-flash hazard should be commonplace. Incident energy calculations and arc labeling of switchgear are a good example of safety culture.

Education of personnel is justified for safety and economic reasons. Arcing faults cause direct damage costs and costs due to process interruption, and when humans are involved, high medical or legal costs are possible.

3.2. Design

Prevention of internal arcs in switchgear starts naturally in design. Requirements have been set in IEC and IEEE standards [1–4]. The IEC standard [1] presents a list of locations where internal arc faults are most likely to occur in metal-enclosed switchgear and controlgear:

- Connection compartments
- Disconnectors, switches, grounding switches
- Bolted connections and contacts
- Instrument transformers
- Circuit breakers

The standard also lists possible causes of internal arc faults and examples of measures to decrease the probability of faults. These measures include both technical solutions and personnel related recommendations. Some additional design options are evaluated below.

3.3. High resistance grounding

High resistance grounding, limiting phase-to-ground fault currents, can be seen as an arc-flash preventive technique. It reduces drastically the dissipated energy, and sustained arcing faults in low voltage (LV) systems. This is why proponents of this system have proposed that it should become a standard of the industry [5].

However, high-resistance grounding is only effective in ground faults and requires that the first ground fault can be cleared before the second ground fault causes phase-to-phase fault [6]. Although majority of arc faults start as phase-to-ground faults, other protection means are necessary when high resistance grounding is applied. Additionally, high-resistance neutral grounding seems to have very limited window of application on medium voltage (MV) systems for several reasons explained in [7].

3.4. Insulated vs. bare busbar

Insulated bus appears to be superior to bare bus, but there are different opinions. First, it is obvious that insulation provides means to reduce the probability of arc faults caused e.g. by falling objects or by vermin. Another advantage is that insulation prevents single-phase faults from escalating to high power multi-phase faults [8].

The third possible advantage is that the arc may travel to insulated area and become self-extinguishing [9]. This is, however, controversial. In tests and real arc faults reported in [10], the arc