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Surface arcing of insulators due to bentonite contamination

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ABSTRACT

Impulse, alternating and direct voltage tests together with optical observations have been done under clean and polluted surface conditions with respect to bentonite, which is treated as a pollutant. The insulator materials tested were polymethyl methacrylate and polythene. Bentonite pollution may affect several surface flashover characteristics such as voltage at breakdown and 50% breakdown voltage under negative lightning impulse (1.2/50 μs) and the time to breakdown under wet condition for both negative and positive impulse voltage. There are four types of paths taken by the discharge channels, based on which the degree of degradation of the material surface may vary.

Introduction

For the last decade, applications of bentonite in electrical engineering have been increasing rapidly due to many of its advantages [1]. There are numerous studies that have been conducted concerning the effectiveness of bentonite as a backfill material in electrical grounding systems [2–4]. Due to its low resistivity and high moisture absorption and retaining capacities, this material has become widely used as a conductivity enhancing material for grounding systems. However, this compound is easily puffed off in air during unloading and mixing operations as the material is available in fine, low density, dust form. Therefore, as the grounding systems are installed at a site, there is a high chance that bentonite dust will transported in the air with wind and settle on a nearby insulator surface. In addition, this airborne pollutant may readily be attracted towards insulators due to electrostatic forces that drive the pollutant along the electric field [5].

A number of investigations on insulation contaminants have been undertaken and published whereby the majority has considered salts as the main artificial pollutant in order to study the characteristics of commercially available insulators [6–9].

Other types of pollution also have been taken into consideration in several studies. For example, soluble-type contaminants such as sugar, lime, etc. and non-soluble contaminants such as metal dust, kaolin, cement, etc. have been studied under dry and wet conditions [10–12].

However, till date, no comprehensive study has been conducted with regard to the effects of bentonite contamination on insulation surface flashover under impulse and alternating voltage conditions.

Therefore, in this study we conducted several experiments to investigate surface flashover characteristics of insulators with bentonite contamination under high voltage conditions (impulse and alternating voltage test). The tests include investigation of the effects of bentonite pollution on withstand voltage ($V_{50\%}$), voltage at breakdown (V_b), time to breakdown (t_b) and the behaviour of arching path of discharge channel.

Methodology

The experimental set-up used in all cases, is shown in Fig. 1. The Marx generator output is connected to an HV electrode that is attached to the insulator while a circular metal plate is used as the grounding electrode. In this experiment, the lightning impulse voltage used has an approximate rise time of 1.2 μs and a half-time value of 50 μs supplied by the Marx generator with maximum voltage levels of up to 400–450 kV. The testing condition of the power supply is set in accordance with the requirements defined in IEC 60060–1 [13]. In the alternating voltage (AV) testing, the Marx generator has been replaced by an alternating voltage transformer which has maximum rms voltage of 400 kV. The experiments have been conducted at three high voltage laboratories; CELP, Universiti Putra Malaysia, TNBR, Malaysia and Universiti Teknologi Malaysia. The laboratories have been selected based on the facilities available and accessibility of equipment during the period of the investigation.

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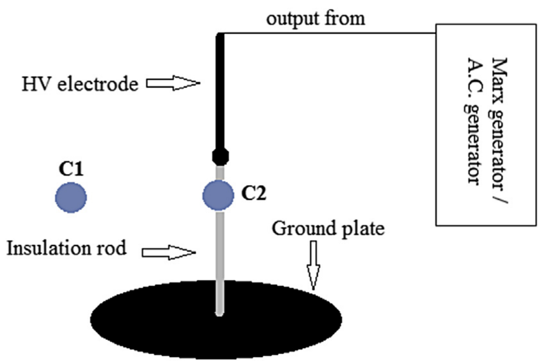


Fig. 1. Side view of schematic diagram of the experimental setup consist of C1: Still DSLR camera Nikon and C2: Video camera (digital) Sony

A still DLSR camera and a video camera were placed in mutually perpendicular directions to capture the arc paths during the flashover events.

The artificial impulse testing will examine the performance of two different insulator material samples, namely acrylic plastic (polymethyl methacrylate abbreviated as PMMA) and polythene for their surface flashover characteristics with and without contamination with relative permittivity 2.35 and 4.55 respectively. The parameters and the profile of these materials are listed in Table 1 below, where D is the diameter, H is the height and L is the creepage distance.

In order to observe the performance of the insulator with and without pollution, the withstand test according to the IEC standard is followed [13,14].

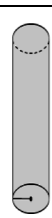
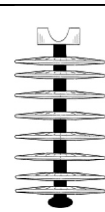
In this study, the contaminant used is Sodium bentonite powder imported from Pakistan. The chemical composition and physical properties of the material have been detailed in Lim et al. [15].

A 5 gm sample of bentonite is weighed using an electronic scale. Then the contaminant is uniformly applied on the insulator surface with a fine brush. During the brushing process, two layers of pollution are applied on each surface to ensure that the layer is uniform as much as possible. Special attention is paid to areas that are difficult to reach especially during the application of the contaminant to the rubber specimen. After the application, excessive powder is blown off by a blower to ensure only a thin layer remains on the insulator surface such as that shown in Fig. 2.

For wet condition, spraying method is used in order to wet the insulator surface to total saturation. The surface is regularly wetted to reach saturation during the event of applying repeated impulses or alternating voltage pulse trains.

During impulse testing, the Up-and-down method is adopted to obtain breakdown voltage [13,16]. The Up-and-down method is usually used in high voltage testing for two main purposes; for calibration, and to determine the $V_{50\%}$. The $V_{50\%}$ was calculated using the following formula from Ref. [13]:

Table 1
Parameter of test specimens.

Type	PMMA	Polythene	Rubber
Pictures			
D(mm)	20	20	150
H(mm)	200	200	500
L(mm)	–	–	1350

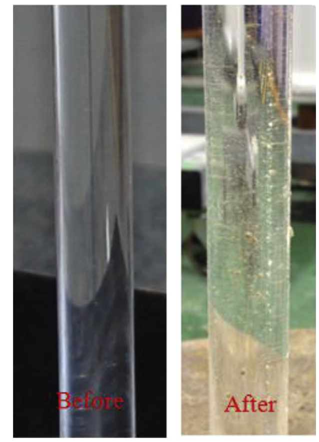


Fig. 2. Clean and polluted insulator.

$$V_{50\%} = V_0 + \Delta V\left(\frac{A}{k_i} - \frac{1}{2}\right) \quad (1)$$

where V_0 was an initial voltage, k_i is the number of events concerned and A was the number of useful tests.

For alternating voltage test, a sustained-low frequency signal is applied at 50 Hz throughout the test. In this test, the voltage is raised slowly starting from a very low voltage of 5 kV then the voltage is raised by the step (Δv) which is 5 kV applied for 10 s. The voltage is increased until total breakdown or flashover occurs. This step is repeated a number of times in order to obtain an average breakdown value.

Results and analysis

Voltage at breakdown

To observe the effects of bentonite presence on the insulator surface, comparison of data was made between a dry and clean insulator surface with a dry and polluted insulator surface (or a wet and clean insulator surface with a wet and polluted insulator surface).

Tables 2 and 3 summarise all the results obtained for voltage at breakdown in highest and lowest point voltage.

In terms of standard deviation, the highest value is 20.9 kV and lowest value is 4 kV. Although many tests were conducted, it seems that the test results still have some dispersion which may be due to different frequencies of breakdown occurrence.

From apparent view, it appears that the absence of bentonite affects the polythene materials more than it affects the PMMA insulator.

In terms of lowest possible breakdown voltage, apparent view shows that insulator with bentonite pollution has lowest value of

Table 2
PMMA impulse test.

Polarity	Surface condition	Highest V_b (kV)	Lowest V_b (kV)	Std. dev (kV)
Positive	Dry clean	136	122	4.77
	Dry polluted	137	118	5.85
	Wet clean	128	116	4.72
	Wet polluted	129	111	4.55
Negative	Dry clean	230	186	13.4
	Dry polluted	257	173	20.9
	Wet clean	162	142	6.18
	Wet polluted	140	122	5.34