JKAU: Eng. Sci., **vol. 11 no. 1,** pp. 109-117 (1419 A.H. / 1999 A.D.)

Pulsative Corona From Fee Spherical Conducting Particles in SF_6 / Gas Mixtures

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Abstract. Pulsative corona discharges from free spherical shaped conducting particles are investigated experimentally using SF_6 and its mixtures with nitrogen N_2, perfluorocarbon $C_8F_{16}O$, triethylamine $(C_2H_5)_3N$ and freon $C_2Cl_3F_3$ gases. Corona inception, particle lift-off and breakdown voltages as well as charge-voltage (q-V) characteristics were determined in these mixtures. The results show that corona characteristics are affected by particle diameter and gas mixtures. Generally, small percentage of these additive gases results in reduced corona charge levels. The particle movement is also observed and reported in this paper.

Introduction

SF_6 insulated high voltage apparatus such as gas insulated substation (GIS) and gas insulated transmission line (GITL) need a high degree of insulation reliability. The insulation strength of such systems can be greatly reduced by the presence of contamination in the form of conducting particles[1]. This behavior has lead to a considerable research interest in the corona and breakdown characteristics of SF_6 and SF_6 gas mixtures containing fixed and free conducting particles[2,3]. These mixtures are reported to exhibit reduced sensitivity to microscopic field nonuniformities and higher corona stabilized breakdown levels as compared to SF_6 gas alone[4,5]. The presence of N_2 in SF_6 tends to reduce the undesirable influence of particles or surface asperities[6,7]. Similarly, SF_6 mixtures with $C_8F_{16}O$, $(C_2H_5)_3N$ and $C_2Cl_3F_3$ show improved insulation strength in nonuniform fields[8].

In a previous report[3], the authors investigated the corona from wire shaped free conducting particles of different parameters and discussed the q-V characteristics for SF_6/ gas mixtures. In this paper, the investigations are extended by using spherical particles and SF_6 mixtures with N_2, $C_8F_{16}O$, $(C_2H_5)_3N$ and $C_2Cl_3F_3$ gases. Corona onset, particle lift-off and breakdown voltages as well as pulsative corona charge levels are measured under different experimental conditions. The particle motion is also observed. The results show that the q-V characteristics are affected by gas composition. Generally, the addition of a small percentage of nitrogen, perfluorocarbon, triethylamine and freon to SF_6 reduces the pulsative corona charge levels and increases the particle-initiated breakdown voltage level.

Experimental System

The measurements were carried out using a transparent, Plexiglass cylindrical pressure vessel of 130mm internal diameter and 520mm height. Concave electrodes of 60mm diameter with an interelectrode gap separation of 13.3mm were used. Sphere particles having diameters ϕ of 3.2mm and 4.8mm were employed. This electrode configuration is used to avoid the particle tendency to migrate out of the gap as a result of their bouncing motion and to obtain a triggered breakdown voltage up to 100 kV.

The high voltage source was a 60 Hz, 100 kV test transformer. A current limiting water resistor was connected in series with the high voltage supply. A partial discharge detector consisting of a coupling capacitor, measuring impedance and a partial discharge meter was used to measure the pulsative corona charge levels. Without the test geometry in the circuit, the system had a partial discharge level of < 5 pC for voltages of 100 kV.

The SF_6 gas used was of commercial purity i.e. 99.8% pure. The total gas pressure was kept constant at 0.3 MPa throughout the investigations to be in conformity with the busbar pressure in practice. The percentage of the additive gas indicated is by volume and was chosen arbitrarily. The experimental investigations are carried out at room temperature of 23ºC.

Charge-voltage (q-V) characteristics were measured for electrodes in the absence of particles. Then these measurements were repeated with particles until corona onset was detected. Subsequently, corona charge levels were measured for different values of applied voltage. Particle motion was observed by using a telescope. In addition to q-V characteristics, particle lift-off as well as breakdown voltages were also recorded.

Results

Pulsative corona charge levels associated with positive (+pC) and negative (–pC) half cycles were measured for SF_6 gas without any particles and with a single particle of ϕ = 3.2mm. Figure 1 shows that without particles corona started at 40 kV with a charge

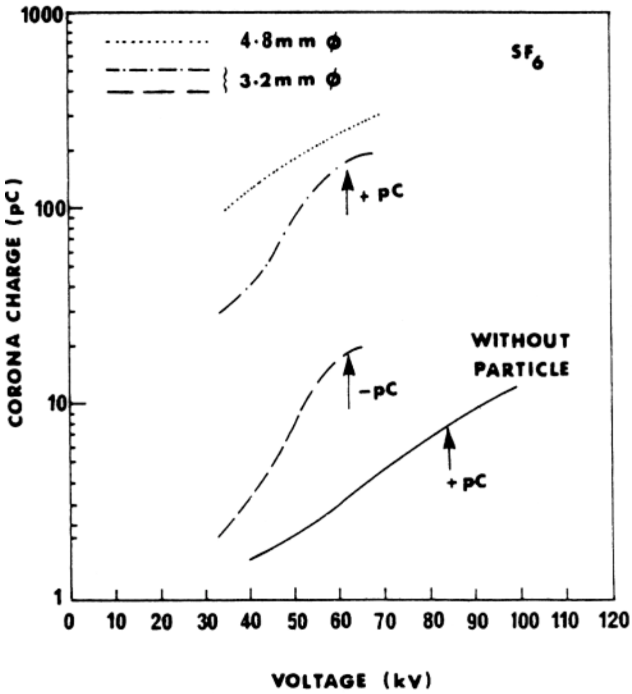

Figure 1. Corona characteristics for positive (+ pC) and negative (– pC) half cycles for two spherical particles in SF_6.

level of 1.5 pC which increases with applied voltage V. With 3.2mm diameter particle the corona initiated at 33 kV with considerably higher pulse charge level. As expected q increases with V and positive corona charge levels (+ pC) are in an order of magnitude higher than the negative corona charge levels (– pC). Moreover, positive corona charge levels measured using particle of ϕ = 4.8mm is also shown in Figure 1. It shows that as particle diameter is increased, the onset voltage increases. Furthermore for a given V, the charge level associated with a bigger diameter particle is more than the corresponding value for smaller particle. At the corona onset, the 3.2mm particle excited a circular motion on the bottom electrode. At V = 45 kV, this particle started to bounce during its circular motion. At 65 kV, the bounce height increased significantly. 4.8mm particle started bouncing on the bottom electrode at the onset voltage of V ~ 35 kV with pulses of 100 pC on the positive half cycle.

With SF_6 / 2.5% N_2 with mixture and 3.2mm diameter particle, corona starts with q = 9 pC on the positive half cycle at V = 25 kV as shown in Figure 2. In this mixture +pC values are lower whereas – pC values are higher than the corresponding values in SF_6 gas. Thus the addition of a small N_2 percentage to SF_6 modifies the positive as well as negative corona pulses. For this mixture, particle started bouncing at 35 kV at the bottom electrode. The bouncing height increased with voltage. However, for this mixture,

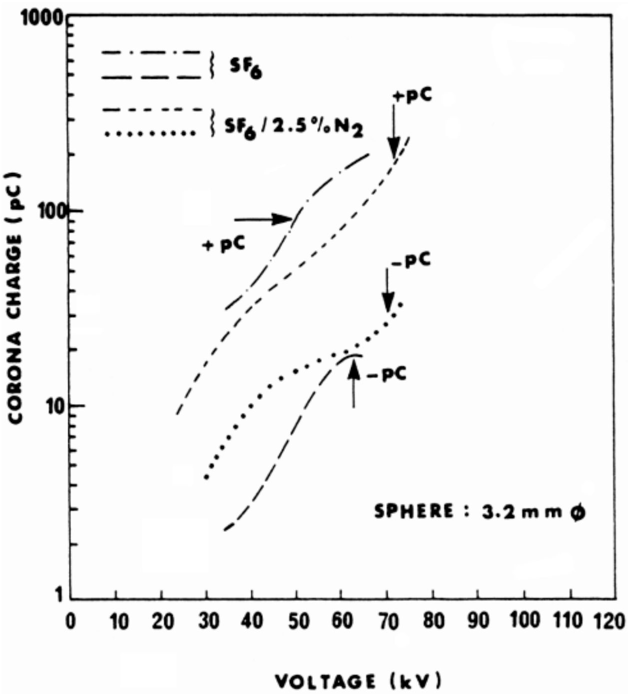

Figure 2. Corona characteristics for positive (+ pC) and negative (– pC) half cycles for one spherical particle in SF_6/2.5%N_2 mixtures.

the circular motion of particle on the bottom electrode which was noticed in SF_6 gas was not observed.

Figure 3 shows the q-V characteristics for SF_6 mixture containing 2.5% and 1.5% of perfluorocarbon vapour for a single spherical particle of 3.2mm diameter. With these mixtures corona pulses were detected at 30 kV (1.5% $C_8F_{16}O$) and 25 kV (2.5% $C_8F_{16}O$) with positive corona charge levels of 1.5 and 11 pC respectively. Generally +pC values for these mixtures are lower and – pC values are higher than the corresponding values in SF_6 gas. Furthermore, the corona levels for the mixture containing 2.5% $C_8F_{16}O$ are higher than the corresponding values for 1.5% $C_8F_{16}O$-SF_6 mixture. In the SF_6/2.5% $C_8F_{16}O$ mixtures, the particle exhibited irregular movement at the bottom electrode at a threshold voltage of 30 kV. The particle motion increased and had a bouncing pattern appears at a higher voltage. In SF_6/1.5% $C_8F_{16}O$ mixture, the particle motion was a noticed at a higher threshold voltage of 50 kV.

Figure 4 shows the q-V characteristics with a single 3.2mm diameter particle present in SF_6 mixtures with triethylamine $(C_2H_5)_3N$ and freon $C_2Cl_3F_3$ additives. Each of these additives had 2.5% content in the mixture. With triethylamine additive, the corona charge at

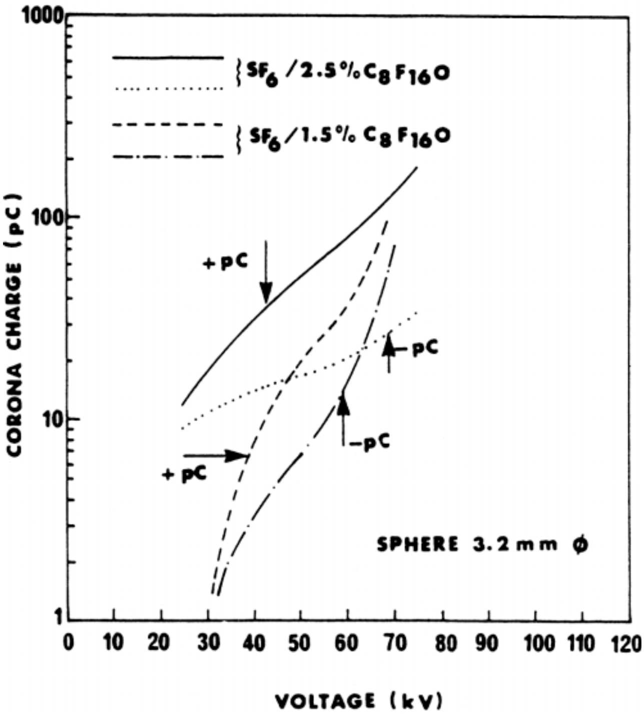

Figure 3. Corona characteristics for positive (+ pC) and negative (– pC) half cycles for one spherical particle in SF_6/2.5% C_8F_{16}) mixtures.

the inception voltage of 25 kV was as low as 3 pC during the positive half cycle. Similar corona charge value is observed for the $C_2Cl_3F_3$ additive but at a higher onset voltage of 30 kV. For both of these mixtures, corona charge increases rapidly with voltage. Also the difference between – pC and + pC values are significantly smaller in these mixtures as compared to SF_6 gas. In $SF_6/(C_2H_5)_3N$ mixture, the particle exhibited circular motion at the bottom electrode starting around 30 kV which later on lead to bouncing motion at a higher voltage. In SF_6-freon mixture only the bouncing motion was noticed.

Discussion

When a conducting particle is in contact with one of the electrodes, it gets charge under applied stress. The particle motion is controlled by electrostatic and gravitational forces. In addition, if corona discharges occur at the particle surface, corona wind becomes an additional force. Generally, under ac stress, the particle lifts off the bottom electrode and assumes a bouncing motion, reaching a height determined by the applied voltage, particle parameters and gas composition. As the applied voltage is increased, the bouncing height as well as corona charge levels increase till a breakdown is trig-

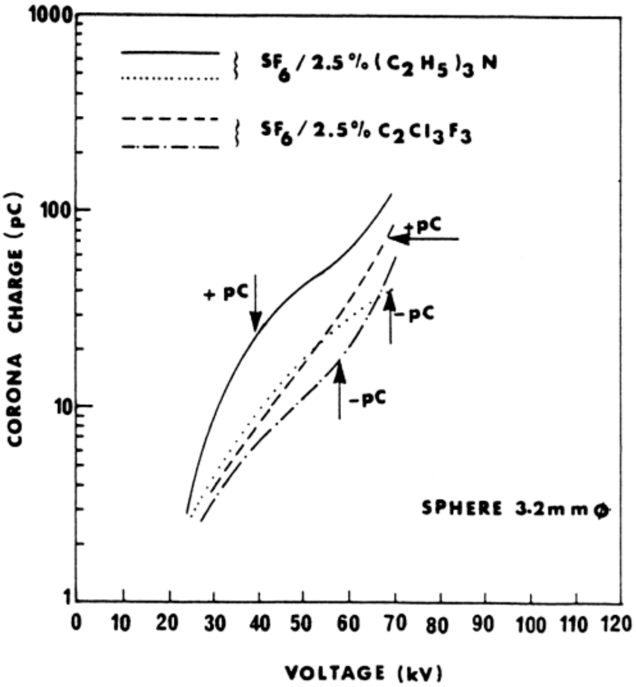

Figure 4. Corona characteristics for positive (+ pC) and negative (– pC) half cycles for one spherical particle in SF_6/2.5% $(C_2H_5)_3N$ and SF_6/2.5% $C_2Cl_3F_3$ - mixtures.

gered when the particle approaches the opposite polarity electrode[9]. Small spark discharges also occur at the instant of a particle-electrode impact[10].

The modes of particle motion as well as required stresses are different in different gases[1]. These results indicate that even a small percentage of an additive can make significant differences in particle motion as well as corona charge characteristics. Generally, the pulsative charge in positive half cycle is higher than its negative half cycle counterpart. In SF_6 gas, this difference in the q values between the two half cycles is very large with +pC values in an order of magnitude higher than the – pC values. Generally, breakdown takes place in positive half cycle in SF_6 gas. Therefore, this large difference in q values may explain the sensitivity of SF_6 to contamination at high gas pressures[1,9]. For the SF_6/gas mixtures investigated in this work, the differences between + pC and –pC values are relatively small. All such mixtures suppress the positive corona pulse levels while increase the negative corona pulse levels. The high electronegative additives whose attachment cross section extends to higher energies than that of SF_6 can cause substantial increase in the negative corona stabilization and lowers the positive corona stabilization[11]. Consequently, these additives reduce the sensitivity of SF_6 gas to microscopic field nonuniformities and increase the corona stabilized breakdown voltage levels. More recent works by the author have studied and discussed the physical properties of such mixtures in a highly non-uniform field[5,12,13]. For the mixtures investigated, particle-initiated breakdown voltages are shown in Table 1. This table further shows the maximum corona charge levels and the applied voltage levels when the particle started motion (mobility mode) and when the particle started lift-off and bouncing motion (bouncing mode). In SF_6 mixtures, the mobility mode starts with a low q value at a lower threshold voltage as compared to SF_6 gas. A similar feature is noticed in the bouncing mode. The higher breakdown voltage of SF_6/gas mixtures shows the improvement of corona stabilization processes. Hence, the additives investigated here exhibit improved particle-initiated breakdown voltages and are good candidates for large scale testing and possible industrial uses[4,6].

TABLE 1. Particle-initiated breakdown voltage and motion modes.

SF_6/gases mixture	Mobility mode		Bouncing mode		Breakdown
	kV	pC	kV	pC	kV
SF_6	33	30	45	45	75
SF_6 / 2.5%N_2	25	9	35	25	92
SF_6 / 2.5% $C_8F_{16}O$	30	18	40	32	89
SF_6 / 2.5% $(C_2H_5)_3N$	30	9	40	25	75
SF_6 / 2.5% $C_2Cl_3F_3$	30	4	45	12.5	83

Conclusions

Small percentages of N_2, $C_8F_{16}O$, $(C_2H_5)_3N$ and $C_2Cl_3F_3$ additives to SF_6 modify the pulsative corona from free conducting spherical particles. Generally, these additives reduces the corona charge levels, and increases the particle-initiated breakdown voltages, thereby making such mixtures less sensitive than SF_6 to the effects of microscopic field nonuniformities. These mixtures also show different particle motion characteristics. Extensive research effort is required to fully understand the dielectric behavior of these mixtures.

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النبضـات الهاليـة الصادرة من الجسيمات الدقيقـة الموصلة الكرويـة الحرة في مخاليط غاز سادس فلوريد الكبريت مع الغازات الأخرى

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المستخلص . تم إجراء دراسة معملية للنبضات الهالية للتفريغ الكهربائي الصادرة من الجسيمات الكروية الدقيقة الموصلة الحرة باستخدام غاز سادس فلوريد الكبريت (SF_6) ، ومخاليطه مع كل من غاز النيتروجين (N_2) ، وغاز فلوريد الكربون ($C_8F_{16}O$) ، وغاز الترايثلامين $(C_2H_5)_3N$ ، وغاز الفريون ($C_2CL_3F_3$) . كما تم تحديد كلاً من لحظة بداية التفريغ الهالي ولحظة بداية تحرك الجسيمات الدقيقة وجهد الانهيار بالإضافة إلى خصائص الشحنة مقابل الجهد (q.v) في هذه الغازات المخلطة . وأظهرت النتائج أن مواصفات التفريغ الهالي تتأثر بقطر الجسيم ونسب خلط الغازات وأن نسبة بسيطة من هذه الغازات المضافة تؤدي إلى انخفاض مستويات الشحنة الهالية . إضافة إلى ذلك فقد تم في هذا البحث ملاحظة وبيان حركة الجسيمات الدقيقة .