بسم الله الرحمن الرحيم

تحليل أداء المولدات فائقة التوصيل باستخدام طريقة النطاق الترددى

نظرا لزيادة الطلب على الطاقة الكهربية كان الاتجاه الى رفع مقننات وحدات التوليد وتغيير بارامتراتها وبالتالى زيادة احجامها . وبالرغم من الافاده في النواحي الاقتصادية من استخدام تلك الوحدات الكبيرة الا ان تغيير بارامترات تلك الالات يوثر سلبيا على اتزان نظم القوى .

والحل المناسب الان للتغلب على تلك المشاكل هو بادخال المولدات فائقة التوصيل والتى تتميز بكفائتها العالية وحجمها الصغير الى جانب امكانية توليدها للطاقة عند جهود عالية تصل الى جهد الشبكة مباشرة .

هذا البحث يدرس اداء واتزان آله فائقة التوصيل متصلة مع شبكة كبيرة خلال خط نقل وذلك باستخدام طريقة النطاق الترددي . حيث تم إيجاد نموذج للنظام في النطاق الترددي وتم استخدام هذا النموذج لعمل تحليل مكثف لاتزان الاله . كذلك تم استخدامه كأساس لتصميم حاكم ملائم يضيف خمد موجب لعلاج ضعف الخمد المصاحب لطبيعة تلك الاله .

اخيرا تم اختبار الحاكم المصمم بتطبيقه على نموذج غير خطي تفصيلي للنظام وقد اوضحت النتائج مدى التحسن الملموس في أداء النظام وزيادة حدود اتزانه عند تطبيق ذلك الحاكم نظرا لما يضيفه من خمد موجب .

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THE RELATIONSHIP BETWEEN CIRCUIT BREAKER PERFORMANCE AND NOZZLE BLOCKING, CONTACT EVAPORATION AND PARTICLE PRODUCTION

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ABSTRACT

Thermal reignition performance data for a two pressure SF_6 model interrupter are presented with peak currents in the range 45-60 kA. Two different nozzle materials and two different test circuit configurations have been used. The results show a strong correlation between a premature degradation in interrupter failure and the presence of tungsten particles produced from the upstream contact and present in the contact gap during the current zero period. The relevance of these considerations to contact designs commonly used in various high voltage circuit breakers is discussed.

1. INTRODUCTION

The circuit breaking performance of gas blast interrupters is known to be strongly dependent on the conditions prevailing in the interrupter nozzle during the current zero period of the fault current waveform. This paper relates to the study of such conditions in an interrupter operating at typical fault currents of 45-60 kA peak. The intention of this study is to distinguish between a number of the various fundamental processes which occur in order to assess their influence on performance. The conditions investigated include both sinusoidal and ramp simulation current waveforms, of 56 kA peak and 1.5 kA respectively, with both copper and PTFE (Polytetra fluroethelene) nozzles in a two pressure SF_6 device. The measurements presented are those of current, voltage and gas pressure distribution along the nozzle length. Other measurements quoted include thermal recovery performance data (in the form of log dv/dt versus log di/dt curves). In particular, circuit breaker performance for a reduced power ramp circuit is compared with that obtained for a full power circuit. This comparison enables the effect of peak arc current on circuit breaker performance to be demonstrated and indicates that early performance degradation may occur if suitable precautions for reducing particulate material ejected from the contacts are not taken.

2. EXPERIMENTAL CONDITIONS

Experimental results have been obtained from a series of tests on a two pressure SF_6 monoblast circuit breaker having the nozzle configuration shown in figure 1. Also shown in this figure are the positions of the pressure measurement sites. Current measurement was by means of a coaxial 0.2 mΩ shunt in series with the interrupter. Voltage measurement was made using a Tektronix type P6015 high voltage probe connected to the upstream electrode. All transient measurements were captured via fast ADC's using a data acquisition system automated using a minicomputer. Further details of the measurement procedure are given in the references [1-3].

The thermal reignition performance of the circuit breaker was determined for both PTFE and copper nozzles under full power test conditions were achieved by means of a conventional LC ringing circuit operating at both 53 and 78 Hz for peak currents up to 65 kA. In each case the nozzle profile and electrode material (elkonite) were the same for each test condition. To ascertain the effect of such high current arcing upon the thermal reignition performance of an interrupter the performance of the nozzle was compared under both full sinewave conditions (described above) and reduced power conditions using a steady 1.5 kA current ramped to zero at various di/dt rates. By setting the current decay rate prior to current zero to a value which corresponds with the rate for a high current half sinusoidal waveform full power performance is simulated without exposing the circuit breaker to the peak current. Since the short circuit testing of high voltage circuit breakers is both time consuming and expensive, the use of this simplified procedure with reduced power levels is attractive particularly for research investigations [4].

3. EXPERIMENTAL RESULTS

Figure 2 shows the measured arc voltage, current and pressure for the case when the nozzle material was copper and for a peak current of 56 kA at a current waveform frequency of 78 Hz[5].The results show pressure increases which are produced by the increased flow impedance caused by the reduction in effective area of the nozzle as the arc cross-section expands in sympathy with the current waveform.

For this reason the pressure rises are greatest at sites P2 and P3 which are immediately upstream and downstream of the nozzle throat where the nozzle cross-section is a minimum. The main pressure transients are complete by 5.5 ms leading to flow recovery before current zero. The results for arc voltage indicate a reduction after 2 ms and a recovery again after 5.5 ms of the current waveform corresponding to the duration of the pressure perturbations. This is also indicative of full nozzle blocking with the arc partially short circuited via the metal nozzle. Figure 3 shows corresponding measurements for the arc voltage, current and pressure in the case of a PTFE nozzle with a peak current of 48 kA. The results are similar to the copper nozzle except that in this case there is no drop in voltage midwaveform. Also the observed pressure transients have a greater amplitude. It is noteworthy that for both nozzles the maximum pressure occurs at 3 ms after arc initiation and that for the PTFE nozzle P_{max} 5 bar which is appoximtately twice that for the copper nozzle (2.5 bar).

The results for thermal reignition performance are shown on figures 4, 5, 6 Figure 4 shows the post-current zero dv/dt versus the pre-current zero di/dt performance data for the model circuit breaker with both PTFE and copper nozzles. Conditions under which the test head cleared and failed to clear are distinguished so that a critical performance band may be established separating the 100% clearance probability from the 100% failure probability. Comparison of the two curves shows that the copper nozzle produces a similar performance to that of the PTFE nozzle. Figure 5 shows the corresponding thermal performance results for the reduced power simulation case with a 1.5 kA current ramped to zero. Results for both PTFE and copper nozzles are again shown. The performance of the two nozzles is similar and satisfies the relationship:-

$$dV/dt = 3.3 \times 10^3 \, (di/dt)^{-2.8}$$

with dV/dt and di/dt in kV/μs and A/μs respectively.

4. DISCUSSION OF RESULTS

The results of figures 2-5 show a number interrelated features. For instance the pressure measurements of figures 2 and 3 suggest that substantial nozzle blocking occurs. However the voltage measurements with the Cu and PTFE nozzles are different. Inspection of the thermal performance characteristics of figures 5 and 6 show nozzle material related effects which are absent for the reduced power, ramped effects. A comparison of the performance data for the two test methods is shown in figure 6. In this case for di/dt > = 20 A/μs there is increasing deviation between the sinewave and ramp results with full power sinewave performance becoming increasingly inferior as the di/dt increases. The mean of the critical performance band in the full power case is well represented by:-

$$dV/dt = 4.6 \times 109 \, (di/dt)^{-7.5}$$

It is not surprising that there should be a performance difference between the full and reduced power effects in view of the nozzle blocking implied by the results of figures 2 and 3. However these latter results suggest that such performance altering effects should have cleared before the initial thermal recovery period. Therefore alternative explanations are needed for the results trends observed. Indeed such flow perturbation effects are utilised to improve performance in puffer and self pressurising circuit breakers.

In order to examine the reasons for this anomaly a more detailed inspection of plasma spectroscopy results during the current zero region reported by El Kholy [5] has been made. These results are for arcing to tungsten copper contacts as in the present case and the results show that the current zero spectra may be of one of two types:-

(i) those showing strong copper emission lines only

(ii) those showing both copper and tungsten lines.

The appearance of the tungsten lines at i=0 in certain current ranges have been shown to be random [5]. By exploring in an approximate manner the statistics of clear/fail during the thermal recovery period, comparisons may be made with the occurrence or otherwise of tungsten lines at current zero. The results show a strong correlation between thermal reignition failure and the occurrence of the tungsten lines in that in the post current zero plasma of those arcs which reignited (i.e. the interrupter failed), tungsten lines are *always* present. It is noteworthy that:

(i) the di/dt (and hence peak current) at which failure becomes persistent corresponds to that at which tungsten lines become persistent,

(ii) if the gas pressure is increased then the di/dt for persistent failure increases as does the di/dt for persistent tungsten appearance - the correlation between the two phenomena being high.

The results presented above have implications for the operation of puffer and self-pressurising circuit breakers. With duo flow operation contact material entrainment into the main arc gap is believed to be reduced. However operation in certain types of puffer modes and even more so in a self-pressurising mode leads to severe nozzle blocking, both in the main and subsidiary (hollow contact) nozzles and generates backflows. The importance and relevance of duo flow operation in removing erroded contact material under such conditions could therefore be limited in the light of these results. The effect in real interrupter units of contact separation during different points on wave and the associated erosion particularly with heavy fault current arcs could in principle exacerbate the situation. However, experiments performed on a commercial puffer breaker [6] using optical fibres to monitor the spectral content of light emitted from the arc in the nozzle indicate that proper interrupter design appears to successfully overcome these difficulties with conventional puffer operation. Although these results do show the presence of copper emission within the throat of a PTFE nozzle (possibly due to the remnant effects of contact movement past the observation point), nonetheless the metallic emission vanishes before current zero for a point on wave switching at the beginning of a current half cycle. Furthermore there is no pronounced increase in the metallic emission when the peak current is increased from 10 to 60 kA peak even at current peak. Taken in conjunction with the present results this confirms that the full performance capability of an interrupter unit is consistent with the absence of metallic emission at current zero and that one performance limiting boundary is likely to be associated with the persistence of particulate tungsten. Thus an adequate performance volume might be envisaged in multi-dimensional space with tungsten particle occurrence as one boundary.

The irregular ejection of the tungsten particles from the interrupter contact has already been established by Siddons [7] as being due to tungsten matrix remaining after the copper has been "leached" due to its lower melting point from the sintered copper tungsten material. High speed framing photographs confirm the existence of such luminous particles at and after current zero [8]. The evidence therefore is that a high concentration of these particles - possibly thermionically emitting and because of their relatively high mass retarding their acceleration with the gas flow - which is responsible for forcing a premature degradation of the interrupter performance at relatively low fault currents (and di/dt). It would then follow that the practice of utilising in various types of circuit breakers may not only enhance the removal of evaporated contact material by a counter flow but also support more diffuse arc - contact current transfer. Such an effect is also apparent in the results for the copper nozzle on figure 2 whereby the arc voltage is significantly lowered. Rotation of the arc along the annular electrode of rotary arc circuit breakers is another example of how such contact erosion and hence tungsten particle emission may be restricted [9].

5. CONCLUSIONS

Pressure measurements along the wall nozzle wall of a monoblast two pressure SF_6 circuit breaker clearly show that during the high current arcing regime the pressure distributions differ from those in the absence of arcing due to the blocking (choking) effect of the arc. During the peak current phase of the fault current waveform the blocking effects for nozzles made from different materials show different features. The performance results presented in this paper show that not only does the performance of a circuit breaker deteriorate with increasing fault current (and hence di/dt) but that this deterioration is independent of nozzle blocking provided the nozzle has cleared before current zero. The evidence is that premature performance deterioration may occur not due to nozzle blocking nor the persistence of evaporated contact material but rather due to the ejection of particulate tungsten from the sintered copper tungsten contacts during the critical thermal recovery phase. Nonetheless the use of hollow contacts in many circuit breaker designs may well reduce the impact of this physical phenomenon although the justification for the use of such contacts may hitherto have been ascribed to quite different reasons (e.g. contact vapour removal and duo flow effects).

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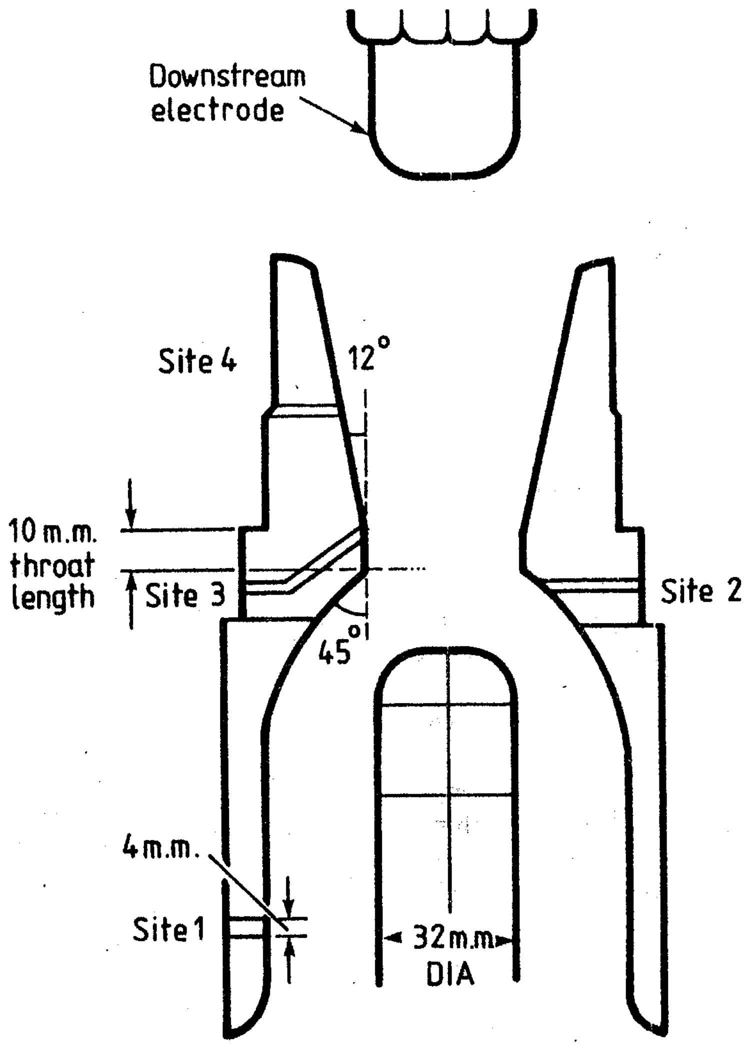

Figure 1 Nozzle and electrode cross-sections showing positions of the downstream and upstream pressure measurement sites.

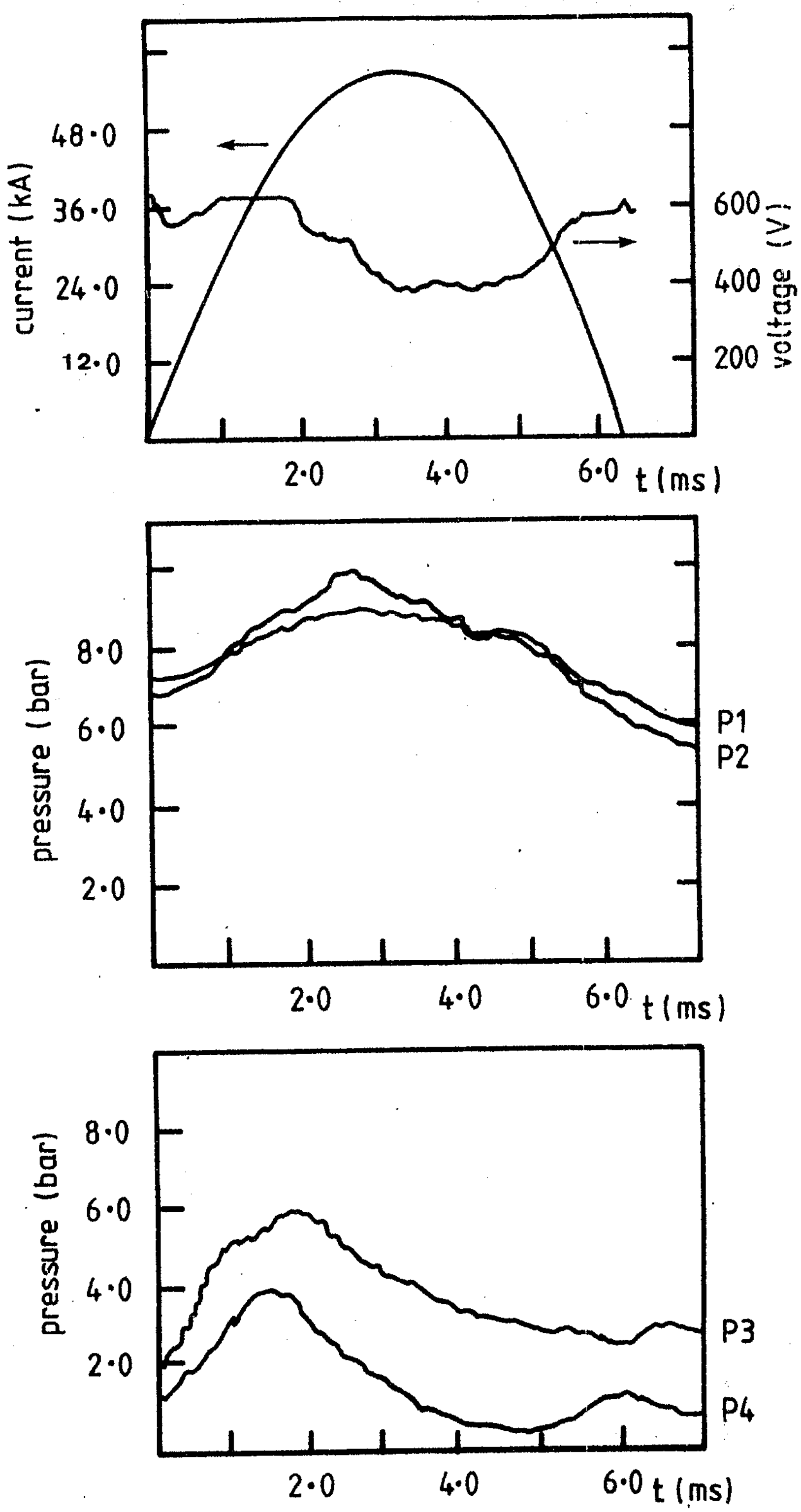

Figure 2 Arc voltage, current and pressure variation with time for the copper nozzle for a peak arc current of 56 kA.

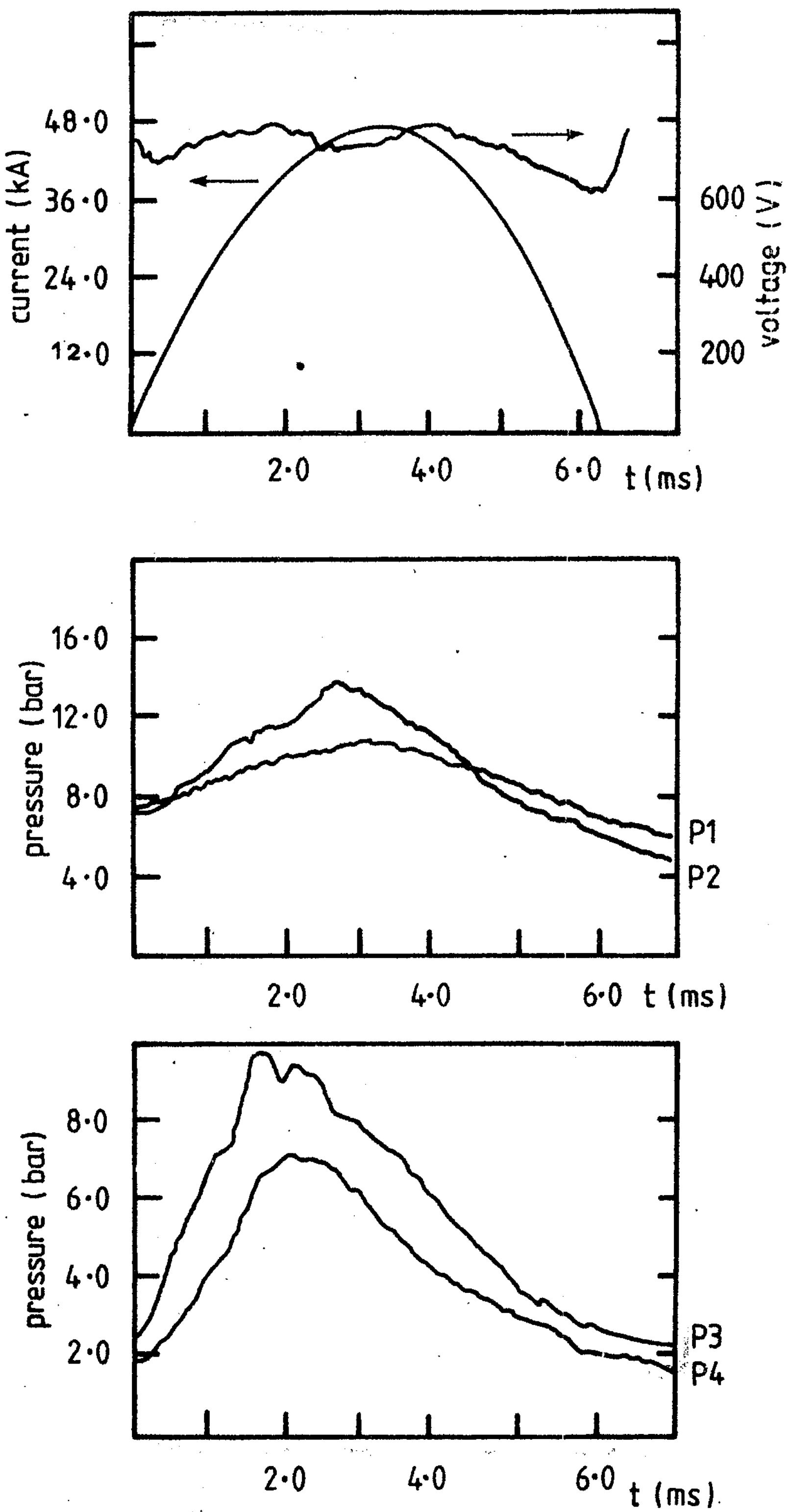

Figure 3 Arc voltage, current and pressure variation with time for the PTFE nozzle for a peak arc current of 48 kA.

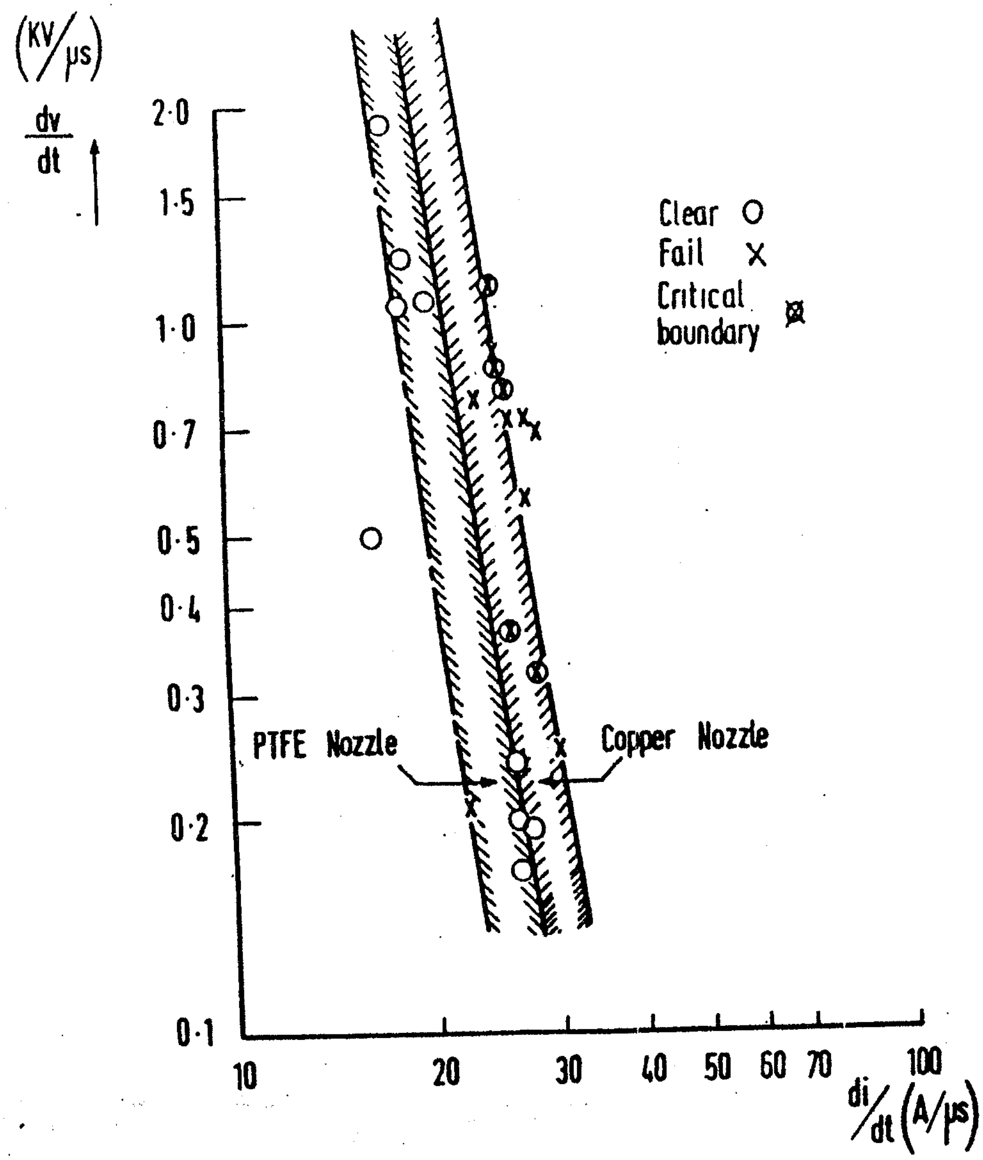

Figure 4 Thermal reignition performance data for the full power circuit (i < = 65 kA) - copper and PTFE nozzles.

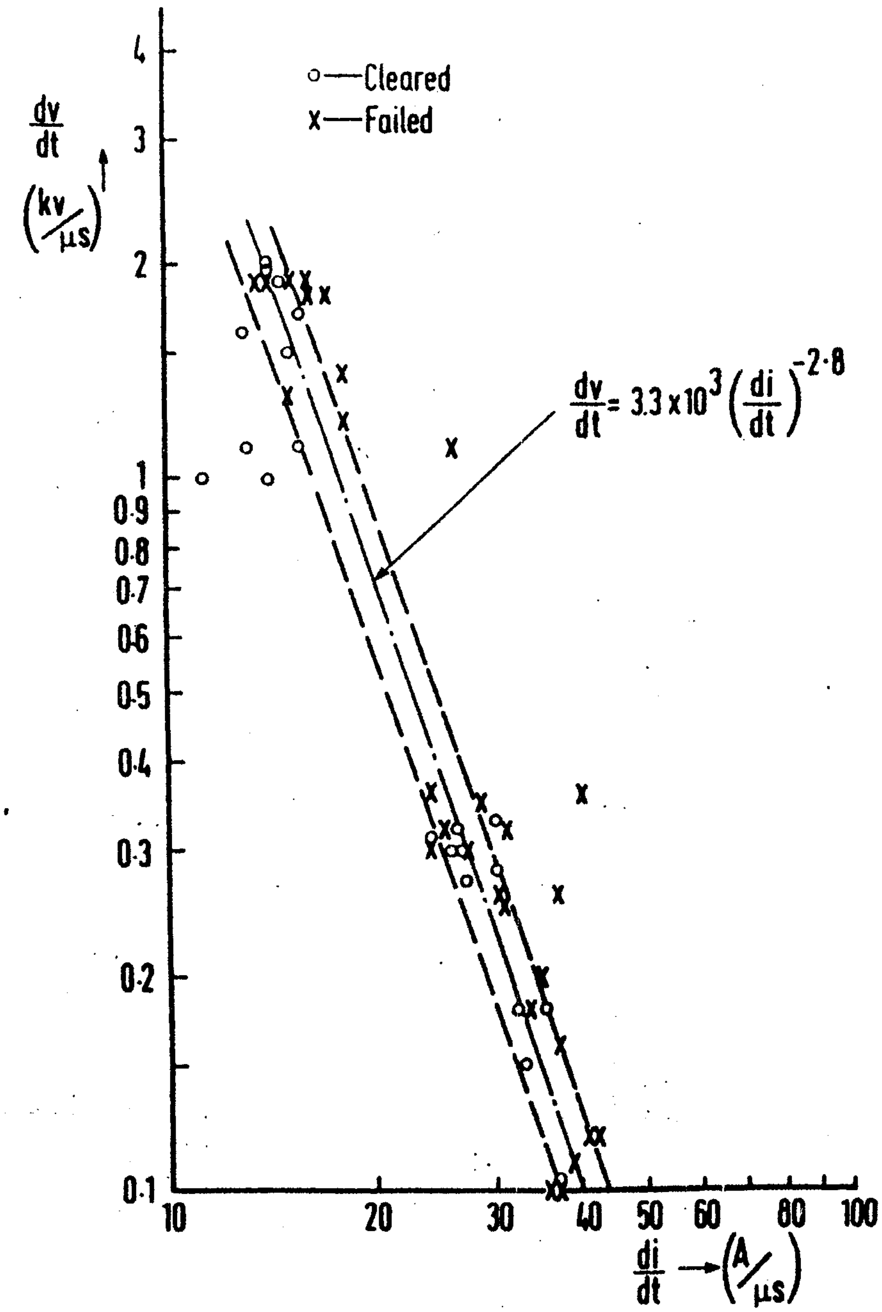

Figure 5 Thermal reignition performance data for the current ramp circuit (i = 1.5 kA) - copper and PTFE nozzles.

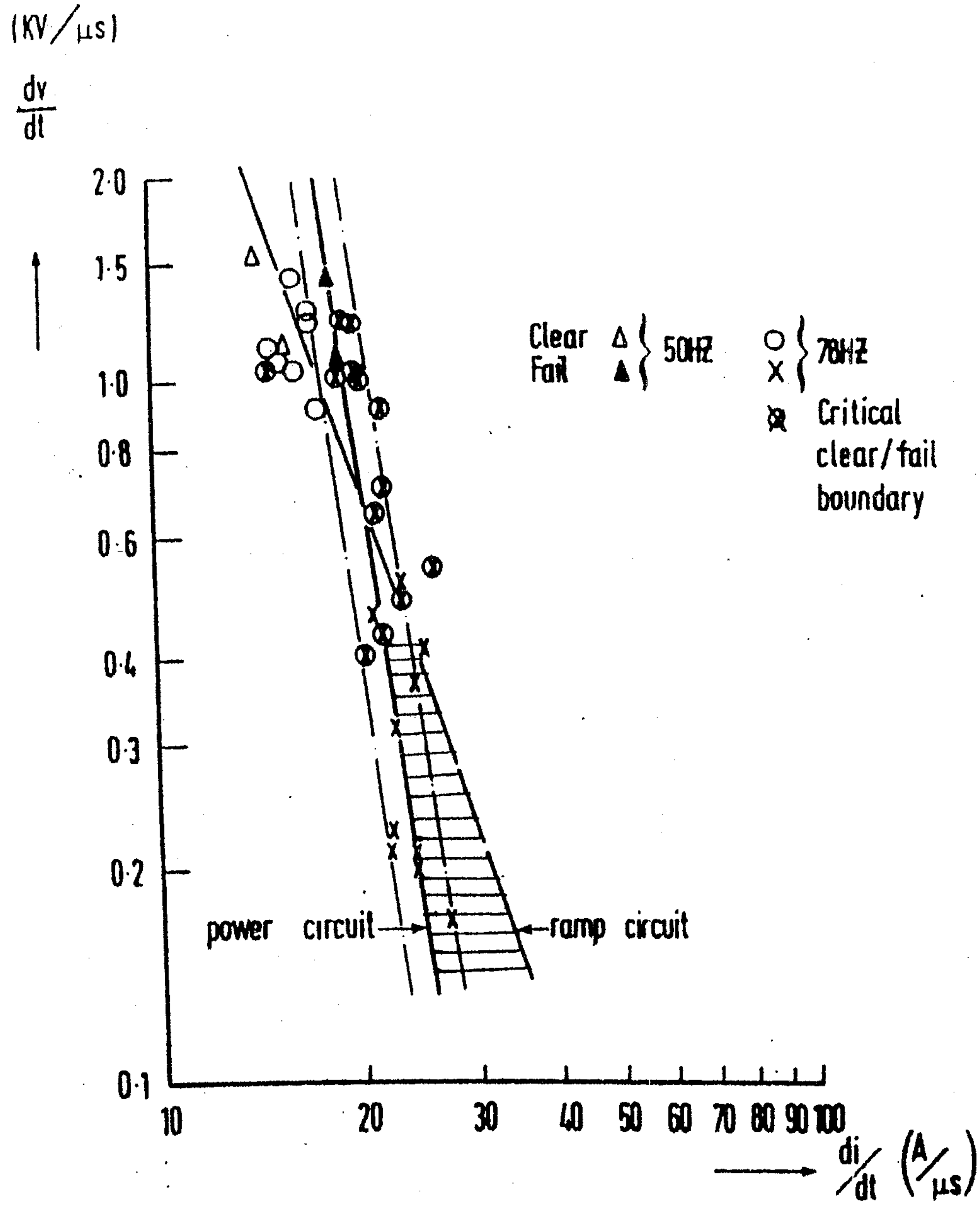

Figure 6 Thermal reignition performance data for the full power circuit (i < = 65 kA) compared to the current ramp circuit .

عنوان البحث :

دراسة العلاقة بين أداء قواطع التيار الكهربى فى حالة وجود ذرات متطايرة من الالكترود والتى تؤدى الى اغلاق المنطقة المحيطة بالقوس الكهربى .

ملخص البحث :

فى هذا البحث تمت دراسة العوامل التى توثر على اداء قواطع التيار الكهربى للقواطع الغازية والتى تستخدم غاز سادس فلوريد الكبريت (SF_6) كوسيط خامل والذى يساعد على قطع تيار القوس الكهربى . وهذا الاداء يعتمد اعتمادا كبيرا على الظروف المحيطة بالقوس والذرات المتطايرة من الالكترود المصنوع من سبيكة من النحاس والتانجستين . وقد تمت التجارب المعملية عند قيم للتيار المراد قطعة تتراوح بين ٤٥ ، ٦٠ ك أمبير كقيمة عظمى وبتردد ٧٨ذ/ث . وفى هذا البحث ايضا تمت المقارنة بين التيارات السابقة وحالة استخدام تيار ذو قيمة ثابتة (٥ر١ أمبير) ويؤول الى الصفر بمعدل من ٢٠ الى ٤٠ أمبير/ميكروثانية وهذة المقارنة لدراسة تأثير القيمة العظمى لتيار القوس الكهربى على اداء القاطع .

وقد اجريت تجارب أخرى أيضا لدراسة تأثير الجزء المحيط بالقوس الكهربى (nozzle) وقد استخدمت لهذة الدراسة مادتى النحاس ، Polytetra Fluroethelene(PTFE).

وقد تم قياس كلا من الجهد والتيار وتوزيع الضغط على طول منطقة القوس الكهربى وفى وجود مختلف الظروف السابقة .

وقد وجد من الدراسة الخاصة بقياس توزيع الضغط عند نقط مختلفة من منطقة القوس الكهربى أن هذا التوزيع عند القيمة العظمى لتيار القوس الكهربى يختلف عنه عند غياب القوس الكهربى وذلك نتيجة لاغلاق هذة المنطقة بسبب وجود القوس الكهربى .