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Making Test of a Fast Acting Earthing Switch for an EHV GIS

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SUMMARY

Gas-insulated switchgear (GIS) uses fast-acting earthing switches (FAES) to ground the line and cable circuits. For safety reasons, FAES are make-proof, i.e. they are able to close on an energized section of the GIS resulting in a short circuit.

This paper presents experience with short-circuit making tests of a FAES for an 800 kV GIS. As synthetic test circuits at rated voltage and subsequent injection of the rated short circuit current are rarely available at EHV/UHV voltage level, test laboratories use one of the following test procedures: (a) preservation of the arcing time at lower source voltage by reducing the SF_6 gas pressure or by using a gas with lower insulation strength, e.g. N_2. The procedure offers the advantage that the FAES does not need to be equipped with an ignition wire. As disadvantage, arc properties at low pressure SF_6 or N_2 are different from the ones at rated SF_6 filling pressure and might lead to unreliable test results. (b) Use of a current source and an ignition wire at the fixed contact, which is as long as the previously determined arcing distance. As the pre-arcing distance between the moving contact and the ignition wire is small, the timing can be easily controlled by the wire's length. The ignition wire's shape, length and mounting method may influence the test results and are discussed. The paper evaluates both methods for the testing of an 800 kV FAES. Method (b) is preferred as making angle and arcing time can be set more reliably than those with method (a). As EHV/UHV FAES are subject to a comparatively long arcing time, usually exceeding 10 ms at rated frequencies, contact ablation and the risk that the arc leaves the arcing contacts due to electromagnetic forces are to be considered in the design. Additionally, electromagnetic forces may reduce the closing speed thus extending the arcing time. Numerical simulations of these forces can help to optimize the test set-up and are discussed in the paper.

As preparation of the making test, the pre-arcing time is determined with rated voltage and a reduced current. The valid making angle to determine the pre-arcing time is ±15° electrical degrees around the voltage peak. As the pre-arcing time is quite unstable using new fixed and moving contacts, a certain amount of conditioning shots is required to stabilize the pre-arcing time and to yield stable results. Alternatively, DC voltage can be used. This paper describes the pre-arcing time determination of an 800 kV FAES.

According to the standard IEC 62271-102 Annex G, the pre-arcing time is one of the most important criteria for the making test. In practice, the pre-arcing distance is more accurate, since even variations in closing speed and electromagnetic forces may change the pre-arcing time, but those still leave the pre-arcing distance largely unchanged.

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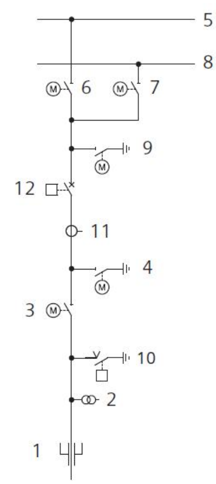
The required making angle (i.e. -40°…+15°) in the standard ensures a consistent pre-arcing energy. As the pre-arcing time for EHV/UHV FAES exceeds 10ms, the exact making instant is less important as the energy during the arcing time is largely independent of the making instant.
The paper reviews the practical implications of the above two requirements for EHV/ UHV FAES.

KEYWORDS
EHV - extra high voltage, GIS - gas-insulated switchgear, FAES - fast-acting earthing switch, short-circuit making test

1 Introduction

FAES (fast-acting earthing switch), a common part of GIS (gas-insulated switchgear), is usually installed on the feeder for either overhead line or cable bay, as item 10 shown in Figure 1[1]. FAES can be used to ground sections of the switchgear, which is similar to maintenance earthing switches. It is also capable of interrupting electrostatically and electromagnetically induced currents which circulate in de-energized overhead transmission lines. Moreover, due to its high-speed closing operation, a FAES is able to close on an energized section of GIS without significant damage to the switch.



1. Bushing
2. Voltage transformer
3. Outgoing feeder disconnector
4. Maintenance earthing switch
5. Busbar 1
6. Busbar disconnector 1
7. Busbar disconnector 2
8. Busbar 2
9. Maintenance earthing switch
10. Fast-acting earthing switch
11. Current transformer
12. Circuit breaker

Figure 1 Single line diagram of typical GIS overhead line bay

As required by IEC standard [2], a FAES with electrical endurance class E1 should be able to make the short-circuit current in two extreme cases without any maintenance: (a) making at the peak of the voltage wave, leading to a symmetrical short-circuit current and the longest pre-arcing time; and (b) making at the zero of the voltage wave without pre-arcing, leading to a fully asymmetrical short-circuit current. This paper presents the more critical case (a) on an 800 kV GIS FAES. Table 1 shows the technical specification of the FAES. The FAES assembled for the making test is shown in Figure 2.

Table 1 Technical specification of 800 kV FAES

Rated voltage	800	kV
Rated frequency	50/60	Hz
Rated normal current	6300	A
Rated lightning impulse withstand voltage phase-to-earth	2100	kV
Rated switching impulse withstand voltage phase-to-earth	1550	kV
Rated power frequency withstand voltage phase-to-earth	960	kV
Short-circuit making current	63	kA
Peak making current	171	kA
Electrical endurance class	E1	

Figure 2 FAES assembled for making test

Figure 3 shows a typical synthetic test circuit with DC voltage source using the method given in section 5.2 of IEC 62271-101[3] for conducting the making operation. The applied voltage on test object and short-circuit current are supplied by separate sources. When the breakdown of the contact gap occurs during the making operation, spark gaps in MD (Making Device, shown in Figure 3) are automatically triggered, causing the short-circuit current to flow through the test object.
Due to the limitations of test laboratory capabilities, synthetic test circuits at rated voltage and subsequent injection of the rated short circuit current are rarely available at EHV/UHV voltage level, e.g. 653 kV peak for voltage source and 63 kArms /171 kApeak for current source for the 800 kV FAES. Therefore, an alternative test method with reduced voltage is used. In order to obtain comparable testing result, the pre-arcing time during the making test with reduced voltage should not be less than that with rated voltage, hence the test is split up into two parts:

(1) A test at rated voltage and reduced current to determine the pre-arcing time;
(2) A test at reduced voltage and rated short-circuit making current, with the required pre-arcing time.

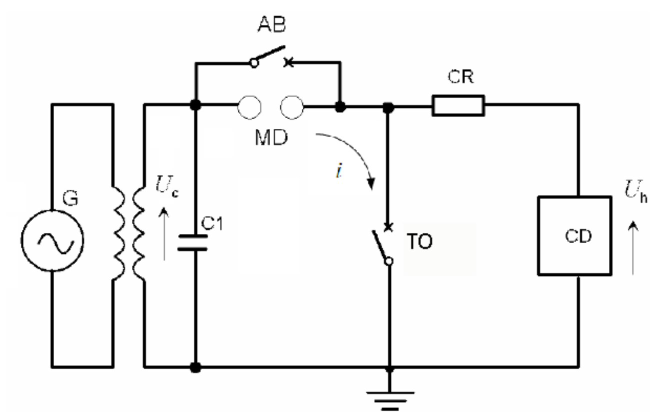


Figure 3 Synthetic test circuit

TO	Test object	MD	Making device
AB	Auxiliary circuit breaker	CD	Charging device
G	Short-circuit generator Capacitor	CR	Charging resistor
C1	of current circuit Power frequency	U_h	Voltage of the voltage source
i	current	U_c	Voltage of the current source

2 Determination of the pre-arcing time

During the pre-arcing test, the current should be low enough causing only a slight ablation on the contact surface. Ten making tests should be performed to determine the pre-arcing time, five with positive polarity and five with negative polarity since pre-arcing time may differ with the polarity of voltage. The valid making angle is ±15° electrical degrees around the voltage peak. The average value of ten valid pre-arcing time measurements *plus* 2σ (standard deviation) is the required pre-arcing time in the making test.

Figure 4 shows the pre-arcing time measurement of the 800 kV FAES with AC test voltage. At the beginning of the test, the pre-arcing time is quite unstable with new fixed and moving contacts. Even with exactly the same settings for the latch release in relation to the applied voltage, the making instant could change from around negative voltage peak to positive polarity in two continuous shots. After certain amount of conditioning shots, continuously valid tests with stable pre-arcing times are achieved. As an alternative, DC test voltage can be used which is much more convenient since the valid making angle is not considered.

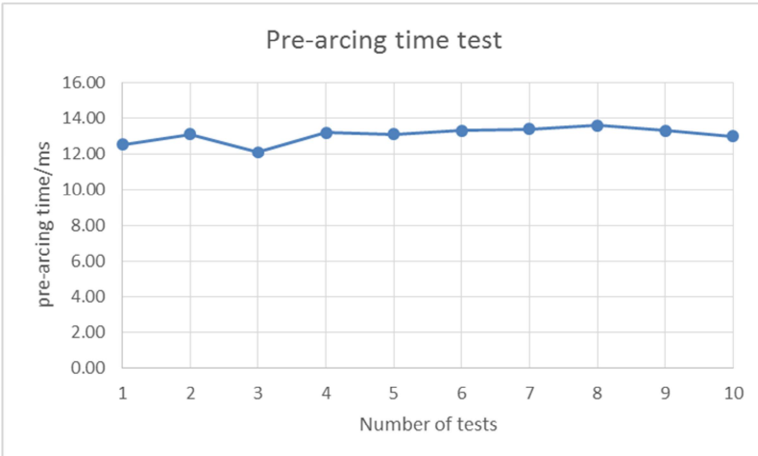


Figure 4 Pre-arcing time measurement
1-5: Positive polarity; 6-10: Negative polarity

The test procedure for pre-arcing determination requires a closing time accuracy of ±0.83 ms to meet the required making angle (i.e. ±15° electrical degrees around voltage peak). The described 800 kV FAES drive is designed with a motor and compressed spring without pre-charging, which has a less precise closing time. A trigger device that stops the mechanism after spring has reached the "dead" point was designed for the making test. Therefore, the closing operation is split into two steps: (a) pre-charging; and (b) releasing with the required closing time accuracy.

3 Making test with reduced voltage

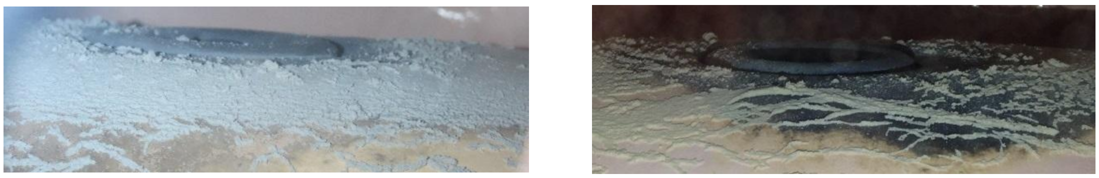
In order to obtain the required pre-arcing time with reduced voltage, the pre-arcing should be initiated at the correct point. Usually there are following two test methods for GIS FAES:

3.1 Test with both reduced voltage and reduced gas pressure

One of the test methods is to preserve the pre-arcing time at lower source voltages by reducing the SF_6 gas pressure or by using a gas with lower insulation strength, e.g. N_2.

The described 800 kV FAES was tested with reduced SF_6 filling pressure during the development. The required voltage corresponding to reduced SF_6 pressure was estimated with the same method as used for determination of the pre-arcing time. The synthetic test circuit shown in Figure 3 was used, the applied voltage comprised DC voltage from voltage source and lower AC voltage from current source. Before the making test, when checking the pre-arcing time with reduced voltage (DC voltage) at reduced SF_6 filling pressure, the pre-arcing time was unstable. It was not possible to obtain a stable voltage value corresponding to the prospective pre-arcing time. Therefore the test was conducted with slightly higher margin in pre-arcing time, but unfortunately the making angle fell out of the valid range, which meant the pre-arcing did not initiate at the right point on wave as expected. It seems that the pre-arcing is less stable at low SF_6 pressure. In addition, as shown in Figure 5, the amount of

arcing by-products (powder) generated by the arc at low SF_6 pressure is much more than that at the rated SF_6 pressure, meaning the arc properties are changing with SF_6 filling pressure.
Above all, this test method has disadvantages compared with the test at rated SF_6 pressure: different arc properties might lead to (a) unreliable test results, e.g. more severe contact ablation; and (b) unstable test results, e.g. unstable making instant. On the other hand, as the advantage, the FAES does not need to be equipped with an ignition wire.

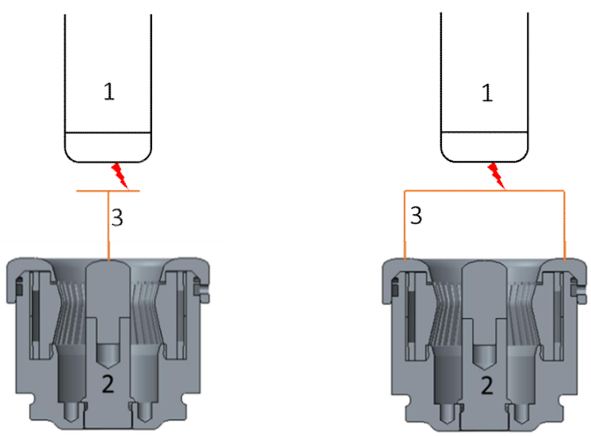


(a) Test at reduced SF_6 pressure (b) Test at rated SF_6 pressure (ignition wire)

Figure 5 Amount of powder on conductor after making test at different SF_6 pressures

3.2 Test with ignition wire

Another test method is to use an ignition wire at the fixed contact which is as long as the previously determined pre-arcing distance to initiate the pre-arcing with a current source.
An ignition wire of different shape could be used according to the arcing contact design and pre-arcing initiation point in the fixed contact, e.g. "T" shape and "U" shape as shown in Figure 6. The diameter of the ignition wire should be not more than 0.5 mm, and a material with sufficient rigidity (e.g. steel) should be selected to provide a suitable mechanical stability. The length of the wire should be the arcing distance corresponding to the determined pre-arcing time *plus* 2σ *minus* the pre-arcing distance between the moving contact and the ignition wire at the chosen source voltage. The ignition wire can be inserted into a hole drilled on the fixed contact, riveting, or any other mounting method as long as it makes reliable electrical contact with the fixed contact and it is convenient to measure the wire's length or re-adjust the shape of wire after mounting.
If the ignition wire is well prepared, the deviation introduced to pre-arcing distance can be less than 2 mm, which is derived from wire length measurement, 2-D wire shape control, tolerance of moving and fixed contacts, etc. This corresponds to a deviation of the pre-arcing time of 0.4 ms at a closing speed of 5 m/s. The deviation is small compared to the determined pre-arcing time.



(a) "T" shape (b) "U" shape

Figure 6 Different ignition wire shapes
1-Moving contact; 2-Fixed contact; 3-Ignition wire

As the pre-arcing distance between the moving contact and the ignition wire is very small with applied generator voltage, i.e. only several millimetres, the timing can be easily controlled by the wire's length. The test method has a disadvantage as the residue of the ignition wire could deposit on a nearby insulator surface reducing the insulation withstand voltage. Consequently, a subsequent condition check could fail.

As the ignition wire method provides a reliable setting of the making angle and the pre-arcing time, this method was chosen for described 800 kV FAES type test and the test was successfully passed with "T" shape ignition wire. The test circuit (Figure 7) is simpler than a synthetic test circuit, as there is only one source required.

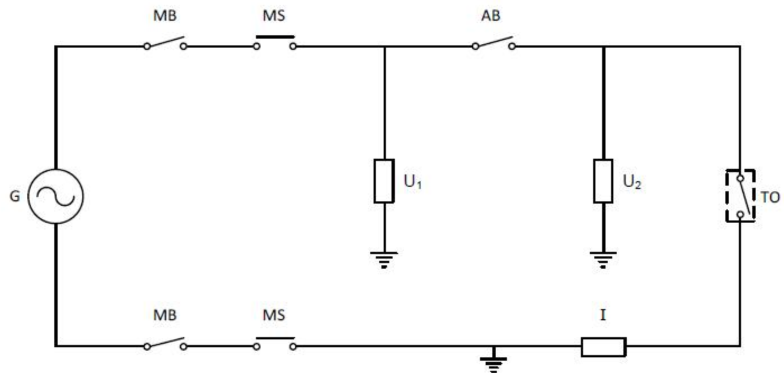


Figure 7 Test circuit with ignition wire method

G	Generator	MB	Master circuit breaker
MS	Making switch	AB	Auxiliary circuit breaker
TO	Test object	U	Voltage measurement
I	Current measurement		

3.3 Influence of electromagnetic force

As EHV/UHV FAES are subject to a comparatively long arcing time, usually exceeding 10 ms at rated frequencies, contact ablation and the risk that the arc leaves the arcing contacts due to electromagnetic forces are to be considered in the design. Additionally, electromagnetic forces may reduce the closing speed, thus extending the arcing time.

Calculation of electromagnetic forces on the moving and fixed parts are key to a sound design. During the development of the 800 kV FAES, several making test set-ups with different current paths and grounding points were calculated in order to obtain a low electromagnetic force on the moving contact. Figure 8 shows an example. Nevertheless, during the making test of the 800 kV FAES, the closing speed was about 5~10% percent lower than that in the no-load test before, resulting in a slightly longer pre-arcing time than the prospective value.

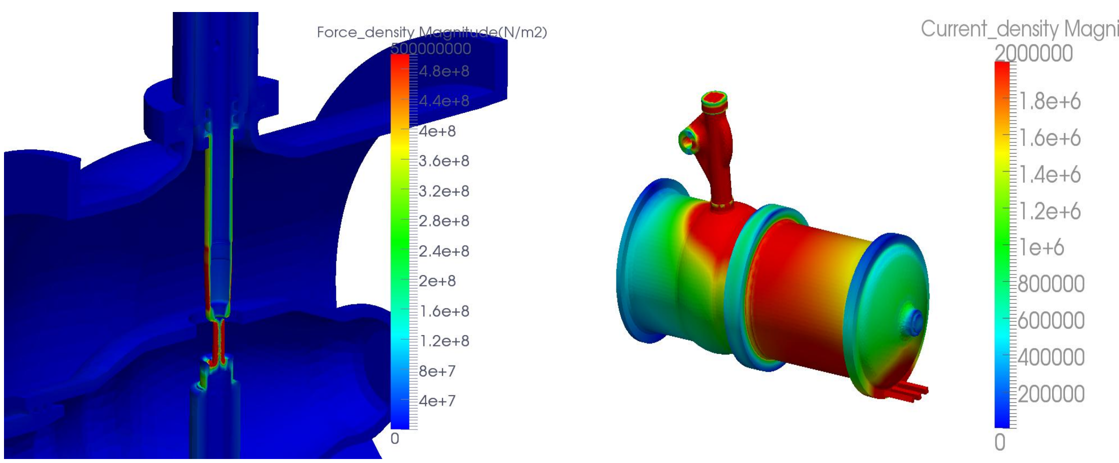


Figure 8 Electromagnetic force simulation

Higher closing speed causes a shorter pre-arcing time, less impact by electromagnetic force and less contact ablation and is beneficial for the making test [4] [5]. On the other hand, the mechanical stress of the damping system and the entire mechanism should be considered.

4 Standard requirement discussion

According to the standard IEC 62271-102 Annex G, the pre-arcing time is one of the most important criteria for the making test when using an alternative test method. However, this requirement is a bit disputable as shown in the following two cases:

(1) The requirement foresees a shorter pre-arcing distance than the prospective one compensating for the pre-arcing time of the test set-up. Electromagnetic forces may reduce the contact speed during the making test and result in a longer pre-arcing time. The test is slightly less severe than the worst case service conditions.

(2) If the closing speed of the FAES for a making test is larger than that for determination of pre-arcing time, the same pre-arcing time requires a longer pre-arcing distance which is more severe than that in service conditions.

In practice, the pre-arcing distance reflects more accurately the service conditions, since variations in closing speed and electromagnetic forces may change the pre-arcing time, but leave the pre-arcing distance largely unchanged.

Another criteria in the standard for the making test is the making angle. Corresponding to the required making angle (-40°…+15°) around voltage peak, ±1.5 ms accuracy in closing time could not be achieved for common FAES drives without a pre-charging design. What is more, some critical factors could cause the making angle to fall out of this valid range, e.g. unstable pre-arcing initiation in the reduced pressure method and imprecisely calculated ignition wire length.

Theoretically, the required making angle in the standard is to ensure a consistent pre-arcing energy. But usually the pre-arcing time for EHV /UHV FAES is long enough that the making angle is less important. The accumulated energies (in terms of integration $\int I^2 t$) during arcing when making at different angles were calculated and compared. As shown in Figure 9, the accumulated arcing energy for making at 20° after voltage peak becomes larger than that for making at voltage peak (E0) when the arcing time exceeds 13 ms. The accumulated energy when making before voltage peak is larger than E0 since the current is much larger at the beginning. Figure 10 shows the calculated break-even point of accumulated arcing energy with different making angles after voltage peak, meaning that if the required pre-arcing time is longer than 13.6 ms, the accumulated arcing energy is always larger than the prospective energy E0.

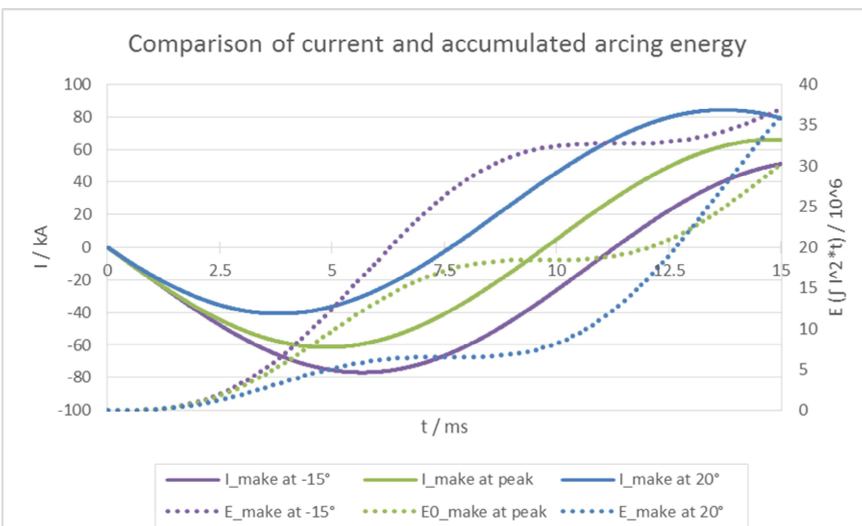


Figure 9 Comparison of current and accumulated arcing energy

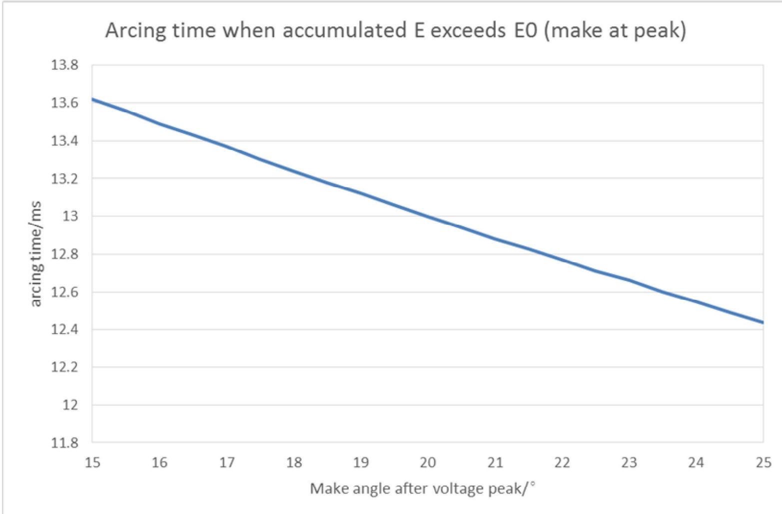


Figure 10 Break-even point for accumulated arcing energy

5 Conclusion

This paper presented the experience of FAES short-circuit making tests for an 800 kV GIS.

(1) As synthetic test circuits with rated voltage and rated short circuit current are rarely available at EHV / UHV voltage levels for FAES making tests, test laboratories use one of the following test methods with reduced voltage: (a) reduce the SF_6 gas pressure or use a gas with lower insulation strength, e.g. N_2; (b) test with an ignition wire. After comparison, method (b) is preferred as making angle and pre-arcing time can be set more reliably.

(2) Numerical simulations could be performed to optimize the test set-up in order to obtain a lower electromagnetic force, thus causing less influence on closing speed and pre-arcing time.

(3) Practical implications of two critical requirements in IEC standard were reviewed and discussed. (a) Pre-arcing distance is more accurate than pre-arcing time as it is largely unchanged. (b) The making angle requirement (i.e. -40°…+15°) is less important for EHV / UHV FAES, since the arcing energy is largely independent of the making instant.

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