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Increasing the Trigger Range

of a Marx Generator

by means of Auxiliary Spark Gaps

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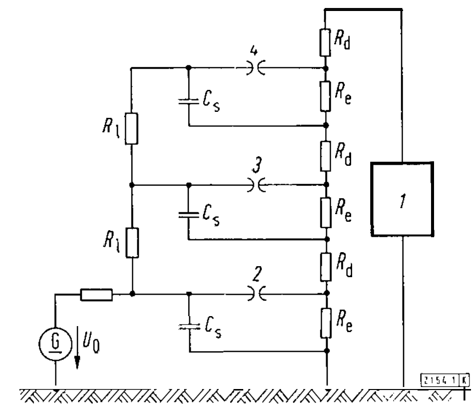
It is well known that the multiplying circuit according to the Marx generator equipped with internal tail resistors R_e (f i g. 1), possesses some favorable features as regards the voltage distribution in the generator and the possibility of parallel coupling of its stages. If several of these are connected in parallel, the time to half value remains practically unchanged as, parallel to the impulse capacitance value increase, there is a decrease of the resultant ohmic value of the tail resistor. This circuit is further particularly adequate for generators having a high total charging voltage, the reason being that voltage drops occurring during the duration of the impulse voltage are distributed over all stages, each of them equipped with a tail resistor R_e and a damping resistor R_d.

However, this circuit also presents a serious liability. It has already been shown [1, 2] that the automatic firing of the coupling spark gaps and therefore the actual feature of the multiplying circuit are no longer insured if tail resistors have an ohmic value of roughly less than 100 Ω; this is actually the case with high energy generators and/or generators having a large number of stages with a low stage charging voltage. Overvoltages which should lead to the firing of spark gaps are, under such circumstances, too low to trigger in a reliable manner. It becomes moreover impossible to obtain a controlled triggering of the coupling spark gaps below their static breakdown voltage, which means that their firing range is very narrow. This range is of the order of a few percents only, whereas it would be desirable to have more than 10 % of the static breakdown voltage. This firing range a_{tr} is given by

$$a_{tr} = (U_{stat} - U_{tr}) / U_{stat}$$

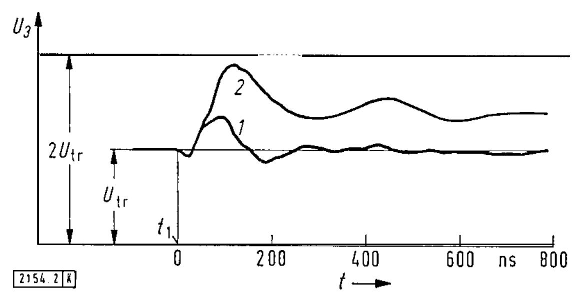
where U_{stat} is the static breakdown voltage of the spark gaps when no firing impulse *is* used, and U_{tr} the voltage at which the spark gaps can be fired with the aid of a firing impulse and a certain dispersion σ_{tr}. For practical purposes of a high voltage laboratory, it is essential that the value of a_{tr} should be larger than the normal dispersion range of all coupling spark gaps connected in parallel; indeed, the object under test 1 can only be tested with a previsible voltage amplitude, by means of a controlled firing of the generator at a predetermined charging voltage. A circuit is described hereafter which possesses also a firing range of more than 10 % of the static breakdown voltage, while nevertheless having the advantages of the one equipped with tail resistor R_e illustrated in f i g. 1, eventhough the tail resistors have a very low ohmic value. The following considerations have led to this new circuit:

1. Papers already mentioned above have shown that the coupling spark gaps 2 to 4 encounter very poor breakdown conditions (a_{tr} = 0 5 %) with tail resistors R_e having an ohmic value of the order of some 100 Ω, while these breakdown conditions become quite fair if the ohmic values of these resistance reach a few thousand ohms (a_{tr} = 20 ··· 30 %).
2. Paper [1] explains the dependence on the values of the tail resistors, in so far that each one of the coupling spark gaps 2 to 4 fires due to an overvoltage which is practically identical with the voltage drop on the corresponding tail resistor. Voltage drops on high ohmic value resistors are more important and last longer than those on low ohmic value resistors. Fig. 2 illustrates, as an example, an overvoltage due to the firing of the second coupling spark gap in a 20-stage, 4 MV, 400 kWs generator equipped either with R_e = 66 Ω or 8 kΩ tail resistors.



F i g. 1. Diagram of a 3-stage Marx multiplying circuit. Resistors arranged according to Edwards and Scoles.

C_s impulse capacitor
R_e tail resistor
R_l charging resistor
R_d damping resistor
U_0 charging voltage
1 test object 2 ··· 4 coupling spark gaps



F i g. 2. Voltages U_3 on the second coupling spark gap 3 of a 20-stage generator as per fig. 1. Spark gap 2 breaks down at t_1 instant; spark gap 3 does not break down; U_{tr} = charging voltage at the instant of triggering.

1 with R_e = *66* Ω 2 with R_e = *8* kΩ

3. The problem would be solved if tail resistors could be available, whose resistance value of some kiloohms would remain constant as long as the coupling spark gaps have not fired, and would then drop to such a value as it should be necessary to form the tail of the impulse voltage.
4. The question arises as to how each tail resistor can realize whether it did or not accomplish its task of firing its respective spark gap. The answer is given by the voltage drop along the resistor. As long as the respective coupling spark gap has not fired, only a

transient voltage appears on the tail resistor, this voltage acting as an overvoltage to fire this particular spark gap. Experience shows that this overvoltage may reach about 40 . . . GO % of the charging voltage U_0 before the coupling spark gap fires. After firing has been achieved, the tail resistor is connected directly in parallel to the charging capacitor C_s, i. e. the voltage on resistor

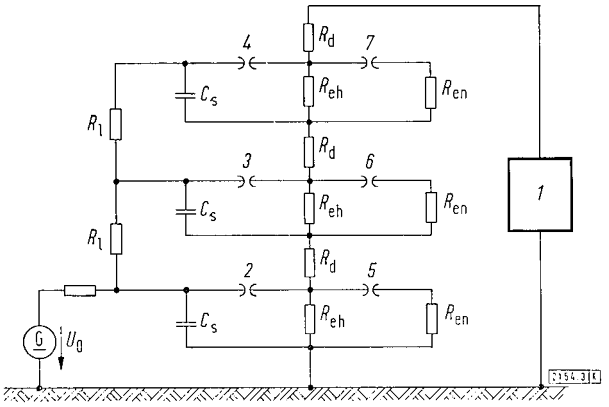


Fig. 3. Marx multiplying circuit equipped with auxiliary spark gaps
R_{en} low ohmic tail resistor
R_{eh} high ohmic tail resistor
5 ··· 7 auxiliary spark gaps
other indications — see fig. 1.

R_e (fig. 1) rises as rapidly as can be allowed by the stray capacitances and self-inductances of the circuit; this voltage has an amplitude of U_0 or possibly even a higher value. With other words, the appearance of a voltage $\geqq U_0$ on the tail resistor can be taken as a proof that the corresponding coupling spark gap has fired.

5. It is therefore logical to start by creating, by means of high ohmic value tail resistors R_e, conditions favourable for the firing of coupling spark gaps: subsequently, the important voltage drop which appears on R_{eh} immediately after the spark gaps have fired, is used to fire an auxiliary gap (fig. 3). This auxiliary spark gap connects a low ohmic value resistor R_{en} in parallel with R_{eh} and thus reduces the active tail resistor to the required ohmic value.

The distance between each auxiliary spark gap 5 to 7 must be chosen so, that the overvoltage which is to fire the corresponding coupling spark gap 2 to 4 does not lead to the firing of the auxiliary spark gaps 5 to 3 breakdown of the corresponding coupling spark gaps. If the distance between the coupling spark gaps is modified, the distance must be naturally modified also between the auxiliary spark gaps. Practical use of this new device depends largely on whether the distance between the coupling spark gaps must be, or not, adjusted with high accuracy. Practical experience gathered on a 20-stage 4 MV, 400 kWs generator has shown that this new circuit is not at all influenced by an inaccurate adjustment of the coupling spark gap distances. Both coupling and auxiliary spark gaps were coupled in such a manner that distances between auxiliary spark gaps were roughly one half of those of the coupling spark gaps. Oscillograms in fig. 4 give an idea of the trigger range of the new circuit. The coupling spark gaps were adjusted, for the recording of a series of oscillograms, for a static breakdown voltage of U_{stat} = 152 kV. The generator was fired, at charging voltages between 150 kV and 105 kV, 10 times at each voltage value by means of an auxiliary spark on the first stage coupling spark gap; high ohmic tail resistors R_{eh} had 8 kΩ each, and those of low ohmic value GG Ω each. The ten oscillograms taken for each value of the charging voltage were recorded one upon another, without film transport, so as to show a time jitter. It can be seen that the trigger range lies between 150 kV and 110 kV, i. e. it has a value of a_{tr} = 27 % if a time dispersion of $\sigma_{tr} \leqq$ 50 ns is allowed. The improvement obtained thanks to the new circuit is particularly evident with reference to the convential circuit (fig. 1) with R_e = 66 Ω tail resistors, Fig. 5 shows oscillograms similar to those of fig. 4. With a time dispersion of $\sigma_{tr} \leqq$ 120 ns, the trigger range reaches only a value of a_{tr} = 7 %. On the whole, the

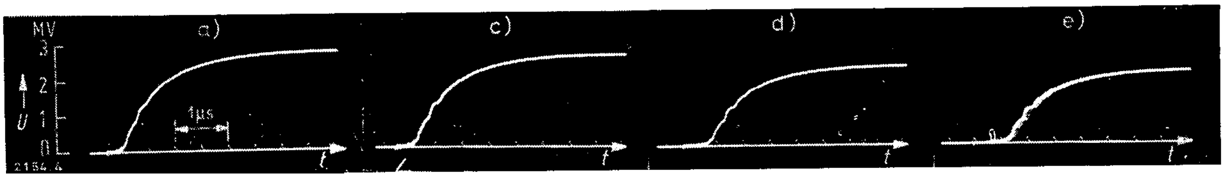


Fig. 4. Triggering of a 4 MV generator with auxiliary spark gaps at different firing voltage values U_{tr}. 10 oscillograms were recorded one upon another for each U_{tr} value [time marks distance 0.5 µs).
U_{stat} = 152 KV, R_{en} = 66 Ω, R_{eh} = 8 kΩ. a) U_{tr} = 150 kV, c) U_{tr} = 140 kV, d) U_{tr} = 120 kV, e) U_{tr} = 110 kV.

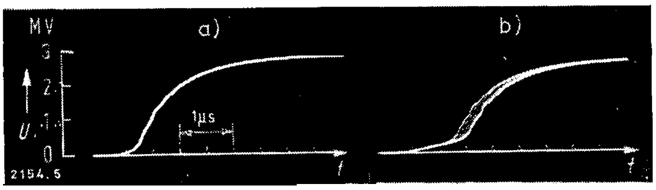


Fig. 5. Triggering of a 4 MW generator without auxiliary spark gaps at different firing voltage values.
U_{stat} = 152 kV R_e = 66 Ω a) U_{tr} = 150 kV b) U_{tr} = 140 kV
other indication — see fig. 4.

generator fires much slower, this fact is brought in evidence by a flat rise of the impulse wave curve.

Nowadays, numerous generators are not only used to produce 1.2/50 lightning impulses, but more and more frequently also for switching surges of the order of 250/2500. It is therefore logical to use in this new circuit a low ohmic tail resistor R_{en} for the forming of a 50 µs tail and, on the other hand, the high ohmic tail resistor R_{eh} for the 2500 µs tail.

To switch over from 50 µs to 2500 µs tail, it will only be necessary just to increase the distance between the auxiliarv spark gaps, so as to be certain that they will not fire

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[1] *Rodewald*, A.: Ausgleichsvorgänge in der Marxschen Vervielfachungsschaltung nach der Ziindung der ersten Schaltfunkenstrecke. Bull. Schweiz. Elektrotechnischer Verein (Bulletin of the Swiss Electrotechn. Assoc.), vol. 60 (1969) pp. 3?-44.

[2] *Rodewald*, A.: Die Zündwahrscheinlichkeit der Schaltfunkenstrecken in der Marxschen Vervielfachungsschaltung. Bull. Schweiz. Elektrotechn. Ver. (Bulletin of the Swiss Electrotechn. Assoc.), vol. 60 (1969) pp. 857—863.

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