

Efficiency and reliability of a repetitive pulse source for continuous pulsed corona processes

Citation for published version (APA):

Smulders, H. W. M., Gompel, van, F. M., Paasen, van, S. V. B., Heesch, van, E. J. M., & Laan, van der, P. C. T. (1997). Efficiency and reliability of a repetitive pulse source for continuous pulsed corona processes. In *10th International Symposium on High Voltage Engineering, Montreal, Quebec, Canada, 25-29 August 1997* (Vol. 6, pp. 393-396)

Document status and date:

Published: 01/01/1997

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.



AUGUST 25 – 29, 1997
MONTRÉAL, QUÉBEC, CANADA

10th International Symposium on High Voltage Engineering
10^e Symposium international d'ingénierie haute tension

Efficiency and Reliability of a Repetitive Pulse Source for Continuous Pulsed Corona Processes

H.W.M. Smulders, F.M. van Gompel, S.V.B. van Paasen, E.J.M. van Heesch
and P.C.T. van der Laan

High-Voltage and EMC Group, Eindhoven University of Technology, The Netherlands

Abstract

Successful introduction of pulsed corona for industrial applications depends very much on the reliability of the high-voltage and pulsed power technology, as well as on the efficiency of energy transfer from the AC-mains to the corona discharge. Furthermore adequate electromagnetic compatibility (EMC) should be achieved between high-voltage pulse source and surrounding equipment. A prototype of an industrial high-voltage pulse source which closely meets these demands has been developed.

Introduction

A high-voltage pulse source recently developed at the Eindhoven University of Technology produces 200 ns wide 100 kV pulses at a maximum rate of 1000 pulses per second. During each pulse 1-2 Joule is transferred to the corona discharge for treatment of gases or fluids; each pulse has a peak power of up to 50 MW. An overall efficiency of energy transfer of 40-70% has been realized. The mean time between failures for the complete apparatus at this time is approximately 50-100 hours; some major improvements are planned to achieve an MTBF of 2500-10000 hours. Patent rights for the design of the pulse source have been obtained [1].

In cooperation with industry several chemical processes [2] are investigated:

- NO and C₂H₄ removal from exhaust gasses
- Styrene, toluene and pentane removal
- Reduction of propane, butane, and trichloroethane

EMC-design

The EMC techniques used in the pulse source are based on the successful concept of constructing a low transfer impedance between common mode currents induced by pulsed power on one hand, and differential mode voltages in signal lines and external AC-mains lines on the other hand. Thus interference-free measurements of fast transients (10 ns rise time), of high-voltage, corona current, and power are obtained. Sensitive apparatus for both electrical and chemical analysis operates reliably close to the pulse source. Computers and networks in

close vicinity and in the surrounding building remain completely undisturbed by the high-voltage pulse source.

Prototype Set-up

The prototype of the high-voltage pulse source developed at the Eindhoven University of Technology consists of five parts:

- Low-Voltage part;
- High-Voltage part;
- Control Electronics;
- Corona Reactor;
- EMC cabinet.

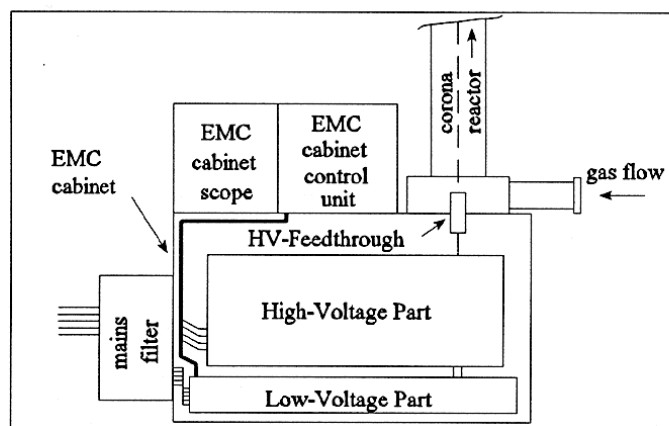


Figure 1 General lay-out of high-voltage pulse source

The main body of the EMC cabinet contains the high- and low-voltage part; the control electronics and digital oscilloscope are housed in a separate cabinet on top (Fig.1).

The corona reactor is a 3.5 m long cylinder placed on top of the main cabinet with in the centre a 3 m long corona wire. For the production of the pulse we use three stages: two resonant circuits coupled by a pulse transformer, followed by a transmission line transformer (TLT) [3] as a third stage. Resonant charging of the storage capacitors through inductors minimizes energy losses. Each stage compresses the pulse duration, and raises the pulse amplitude.

Low Voltage Part

The energy from the three phase AC-mains flows through a rectifier to the smoothing capacitor C_0 (Fig.2). Each single pulse sequence starts by firing of thyristor 1. Thus capacitor C_1 is resonantly charged through inductor L_0 (air coil). The firing of thyristor 2 discharges C_1 via the pulse transformer.

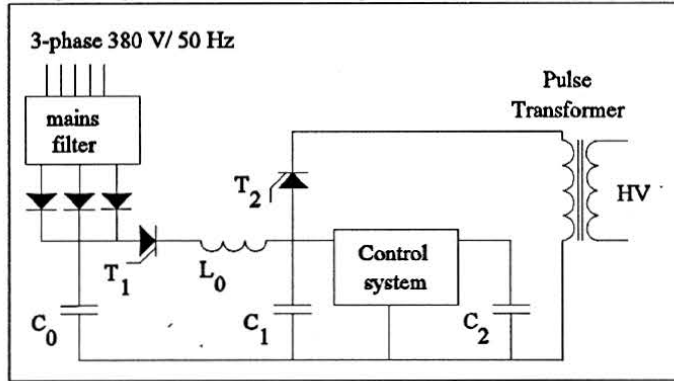


Figure 2 Low-Voltage part, energy transfer from AC-mains to pulse transformer

The energy stored in C_1 (3.0 to 3.5 J) is transferred to the high-voltage part to produce the high-voltage pulse. After each high-voltage pulse a part of the energy returns to C_1 . The surplus of energy depends on the breakdown voltage of the sparkgap in the high-voltage part.

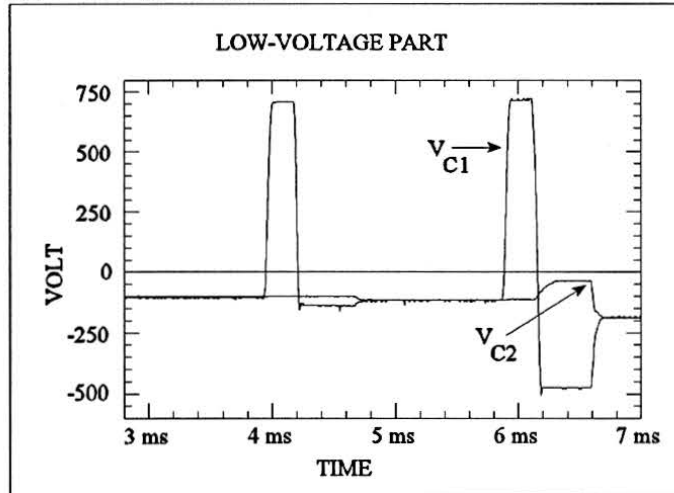


Figure 3 Voltages on C_1 and C_2

A control system adjusts the voltage on buffer capacitor C_2 before this surplus energy (stored in C_1) is shared by C_2 for energy efficient use in the next pulse.

The functioning of this system can be seen in figure 3; clearly at 4.2 ms, when the sparkgap breaks down at a relatively high voltage, almost no energy returns to C_1 ; at 6.2 ms when the sparkgap breaks down at a relatively low voltage, the surplus energy recharges C_1 to nearly -500 V. The voltage at C_2 now is adjusted after which the returning energy is shared by C_2 . The control system thus optimizes the energy efficiency of the low-voltage part.

High-Voltage Part

The main components of the high-voltage part are a pulse transformer, sparkgap, HV-capacitor and TLT (Fig.4). The capacitor C_{HV} is resonantly charged via the pulse transformer up to 30-35kV. The pulse width is approximately 40 μ s (Fig.5). The sparkgap has a low inductance (60 nH). It is semi free-

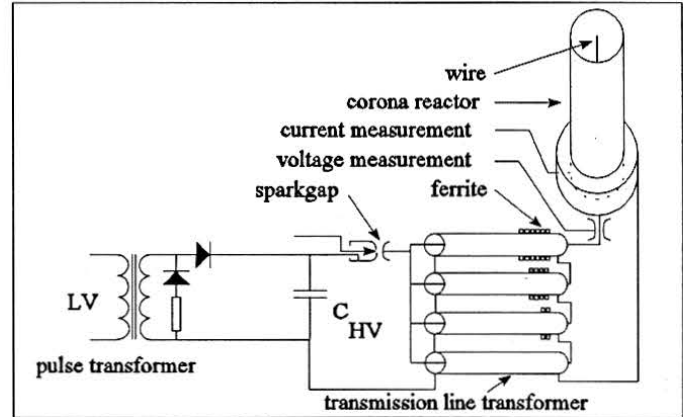


Figure 4 High-Voltage part, energy transfer from pulse transformer to corona reactor via sparkgap and transmission line transformer

running; triggering is added however to force breakdown when necessary. The reliability of the sparkgap is excellent, after 10^9 pulses (total transferred charge 200 kC) only minor

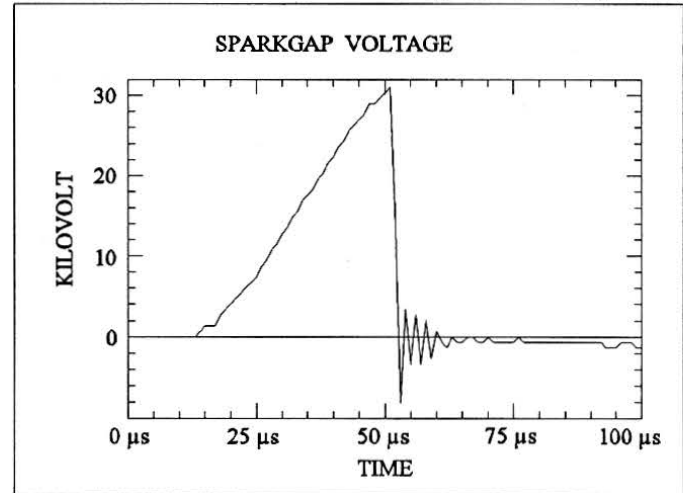


Figure 5 Voltage on capacitor C_{HV}

electrode wear is visible. The gap transfers the energy stored in capacitor C_{HV} to the TLT, 4 coaxial cables, each 20 m long. At no load the TLT multiplication ratio is approximately 5.5, resulting in an output voltage of 160 kV (200ns wide, 10ns risetime). Loaded by corona the voltage is 100 kV.

Corona Reactor

The gas to be cleaned flows through a 3.5 m long stainless steel tube, inner diameter 250 mm. The inside wall is smooth or can be fitted with needles. The centre electrode is a 3 meter long wire, diameter 0.25-1.0 mm, or a steel M8 stud. The

base of the reactor forms a one turn Rogowski-coil to measure the corona current. The centre wire is fed into the reactor via a HV-feedthrough, which also contains a capacitive sensor to form a DI-measurement system for the corona voltage [4].

Measurements

Several wide band DI-measurement systems are used to monitor the pulse source. Examples of measurements can be found in Figs. 6,7. Accurate and interference-free registrations of the voltage and current are needed to calculate the energy transfer to the gas (Figs. 8,9). During extensive series of experiments we tested the influence on the discharge behaviour and on the chemical efficiency for various electrode geometries and polarity. We also analyzed overall efficiency. Some results can be found in Table 1. A report on fast transient current, voltage and E-field measurements of our corona process can be found in [5]. The chemical efficiency of the energy transferred to the gasflow was determined by measuring the conversion of NO. The gasflow was approximately 80 m³/h and the NO input concentration was 200 ppm.

Discussion

The main goal of the pulse source is the efficient and reliable removal of contaminants from a gas or liquid flow. To analyze the efficiency we can split the total process in:

1. High-voltage pulse generation;
2. Conversion of high-voltage energy to the gas by means of corona discharges;
3. Conversion of discharge energy to the chemical process.

We express the chemical efficiency as the converted mass of NO per kWh of corona energy. The experiments show this efficiency is rather independent of electrode geometry and polarity.

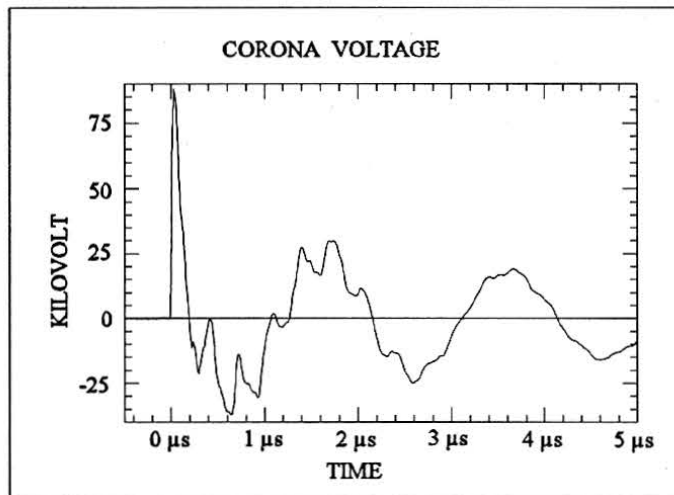


Figure 6 Corona Voltage, positive, wall: needles, centre: wire 1mm

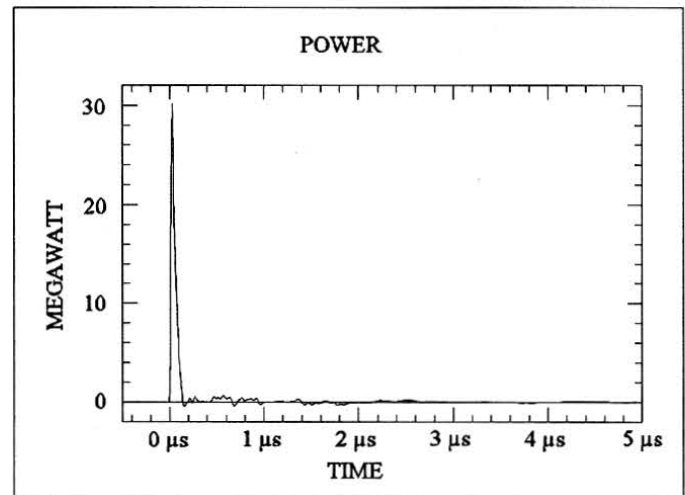


Figure 8 Corona Power, calculated from Figures 6 and 7

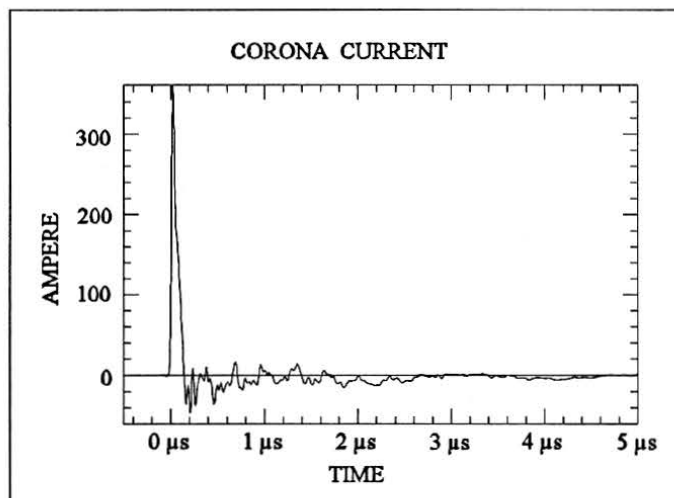


Figure 7 Corona Current, positive, wall: needles, centre: wire 1mm

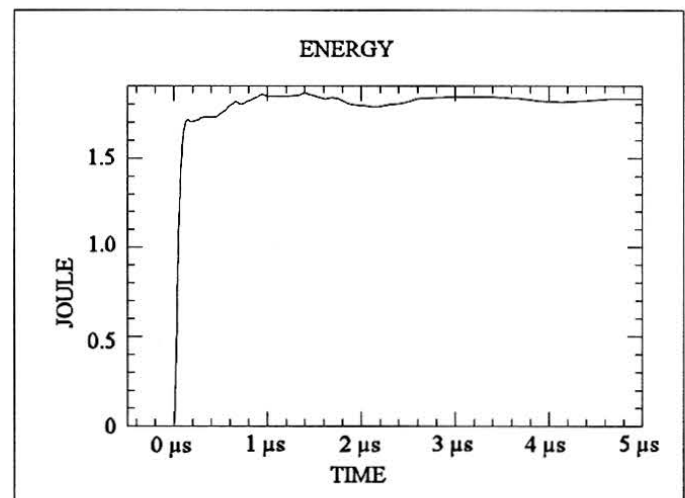


Figure 9 Corona Energy, calculated from Figure 8

Table 1 Efficiency and electrical performance of the pulse source as a function of different electrode geometries and polarity

| Polarity | Corona Reactor | | Electrical Performance | | | | Efficiency | | | | | | |
|----------|----------------|------|------------------------|------------|-------------|----------------------|----------------|-----------------|-------|---------------------------------|--------------------------------|-------------------------------|------------------|
| | Wall | Wire | V peak [kV] | I peak [A] | P peak [MW] | Energy per pulse [J] | Electrical | | | Chemical | | | |
| | | | | | | | Mains to 30 kV | 30 kV to Corona | Total | Reduction/corona power [gr/kWh] | Reduction/mains power [gr/kWh] | Specific Energy [kWh/kg NOin] | Fraction Removed |
| pos. | needles | 1 mm | 83 | 362 | 29 | 1.73 | 0.87 | 0.54 | 0.47 | 32 | 14.9 | 26.8 | 0.852 |
| pos. | needles | M8 | 90 | 533 | 43 | 1.61 | 0.77 | 0.56 | 0.43 | 28 | 12.2 | 26.8 | 0.812 |
| pos. | smooth | 1 mm | 86 | 375 | 29 | 1.61 | 0.84 | 0.53 | 0.44 | 34 | 15.0 | 24.0 | 0.812 |
| pos. | smooth | M8 | 94 | 577 | 49 | 1.84 | 0.86 | 0.59 | 0.51 | 23 | 11.9 | 27.3 | 0.638 |
| neg. | needles | 1 mm | -95 | -339 | 28 | 1.08 | 0.78 | 0.38 | 0.30 | 31 | 9.2 | 15.9 | 0.492 |
| neg. | needles | M8 | -87 | -330 | 26 | 0.90 | 0.71 | 0.34 | 0.24 | 26 | 6.3 | 19.4 | 0.503 |
| neg. | smooth | 1 mm | -99 | -332 | 28 | 0.96 | 0.79 | 0.33 | 0.26 | 32 | 8.5 | 14.3 | 0.456 |
| neg. | smooth | M8 | -93 | -373 | 32 | 1.13 | 0.82 | 0.38 | 0.31 | 30 | 9.4 | 16.6 | 0.506 |

The efficiency of process 2 varies between 0.33 and 0.59, and in a special case with an 0.25 mm wire it even reached 0.80. The polarity is an important parameter; a positive wire allows a better energy transfer. The efficiency of the pulse generation process 1 is independent of polarity and varies between 0.71 and 0.87, affected by the fine tuning of C_1 , the control system and the sparkgap. The overall performance, considering overall efficiency and fraction NO removed, is best for a positive wire and a wall with needles.

The reliability of the pulse source is determined mainly by the high-voltage part. The low-voltage part and the pulse transformer functioned well during the complete experimental program. The sparkgap shows little electrode wear: a mean time between failures of 10^{10} pulses should be possible. Problems are caused by the TLT. The coaxial cable breaks down after approximately 50-100 hours, probably due to partial discharges. Improvements that are planned for the TLT should raise the mean time between failure to more than 2500 hours.

Conclusions

The high-voltage pulse source developed at the Eindhoven University of Technology meets most of the demands imposed by industrial use. The overall efficiency is good, the decisive factor being the transfer of energy from electrical system to the gas; further improvements are possible. The efficiency of the chemical process is independent of geometry and corona polarity. The best overall performance is obtained with a positive wire and a wall with needles.

The reliability is determined mainly by the life time of the cable of the TLT, other parts of the pulse source including the sparkgap show good behaviour. The EMC of the setup is excellent, even very sensitive equipment in close vicinity of the pulse source is not disturbed. Further work will aim at: raising the overall electrical efficiency and improving the reliability of the TLT. Thus this new technology for cleaning gas and liquid flows should become attractive for industrial usage.

Acknowledgment

The investigations have been supported by: The Netherlands Technology Foundation (STW) and the companies Convex and Frigem Energiediensten. The assistance of Mr. A.J.P.M. Staring for chemical analysis and of Mrs. Haiyan Li for work on the pulse source is very much appreciated.

References

- [1] E.J.M. van Heesch, H.W.M. Smulders, R.H.P. Lemmens, P.C.T. van der Laan, "Inrichting voor het behandelen van gassen of vloeistoffen met gepulste corona-ontladingen", Nederlandsch Octrooibureau, 1996. Dutch Patent Application No. NL 1001732.
- [2] S.V.B. van Paasen, H.W.M. Smulders, A.J.P.M. Staring, K.J. Ptasinski, F.M. van Gompel, E.J.M. van Heesch, "Decomposition of VOC's in a Continuous High-Voltage Pulsed Corona Process", paper to be published at *10th International Symposium on High Voltage Engineering*, Montreal, Canada, August 25-29, 1997, paper No. 3333.
- [3] I.A.D. Lewis and F.H. Wells, "Millimicrosecond Pulse Techniques", 2nd Ed., Pergamon Press, London 1959.
- [4] G.G. Wolzak, "The Development of High-Voltage Measuring Techniques", Ph.D. thesis Eindhoven University of Technology, December 1983.
- [5] P.P.M. Blom, H.W.M. Smulders, E.J.M. van Heesch, P.C.T. van der Laan, "Electrical and Optical Analysis of Fast Transient Discharges in a Pulsed Corona Pilot Unit", paper to be published at *10th International Symposium on High Voltage Engineering*, Montreal, Canada, August 25-29, 1997, paper No. 3319.

Address of main author

High-Voltage and EMC group, Department of Electrical Engineering, Eindhoven University of Technology. P.O. Box 513, 5600 MB Eindhoven, The Netherlands. Phone +31402473993, Fax +31402450735