

Modeling ozone generators by using SIMULINK

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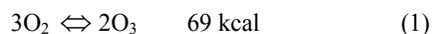
The use of ozone as oxidizer implies the building of reliable ozone generators with permanent operation, result which is obtained by running through the stages MODELATION-SIMULATION-OPTIMIZATION. The ozone is produced through Corona discharge in high voltage alternating current through an air or oxygen jet of low humidity contents. Within this paper we present the modeling of an ozone generator by using the SIMULINK module within the Matlab program. The simulation results are compared with the results of the experimental measurements on a generator built according to the same simulated electrical scheme as the one on which the simulation was performed.

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1. Introduction

The removal of hazardous organic pollutants from drink and waste water for consumption is one of the pressing issues in the environmental research work. The organic pollutants, present in water can be effectively removed with advanced oxidation processes, linked with hydroxyl radicals, ozone and ultraviolet radiation. The generation and use of these methods are one of the most important types in physical methods for water treatment. The ozone is one of the two allotropic forms of oxygen and it's made by symmetrical placed three oxygen atoms. The use of ozone in physical processes is based on its high potential to oxidize organic substances, by turning them into non-hazardous (de-polluted) water to human health. The ozone is one of the strongest oxidants, ranking 4th in the scale of redox potentials: as fluoride or hydroxyl radicals and oxygen atoms. Ozone is relatively unstable in aqueous solutions. He decomposes continuously, but slowly in oxygen according to a pseudo first-order equilibrium. Shelf-life of ozone concentration in distilled water at 20 °C is considered to be 20 up to 30 min [1]. The industrial production of ozone is the placed in the place of use, due to its instability and is usually done by two established methods, by CORONA discharging and the action of ultraviolet light with a wavelength below 220 nm. If oxygen or air is passed through an electric discharge or is exposed to ultraviolet radiation, part of oxygen is dissociated and so the ozone is produced by the following reaction:



so to get a gram of ozone, around 0.827 Wh energy is needed.

The oxygen molecules dissociates into an atomic O₂:



Double and triple collision of atoms leads to the ozone formation. In addition the collisions between oxygen atoms and oxygen molecules may also produce ozone. But a small number of already formed ozone molecules also can be destroyed by these collisions. So that, statistically, only a portion of the existing exposed oxygen in the gas flow is converted to ozone. Ideally, the energy efficiency of production of ozone in gaseous oxygen its about 10 % up to 12 % and the air does not exceed 5 %. For this reason, it's very important to operate the ozone generator in optimum parameters, in order to reduce specific energy consumption. After the design stages, the device is to go through modeling, simulation and optimization.

2. Presentation

The production of ozone is mainly done with the use of CORONA discharge rely, which is a discharge of high voltage (alternating current) in a stream of air with low humidity or oxygen in a transit system. In terms of the used discharge parameters, the CORONA generators can be divided into three basic categories:

- low frequency generators (50-500 Hz);
- medium frequency generators (500-5000 Hz);
- high frequency generators (> 5000 Hz).

The basic cell of an ozone generator is based on the CORONA effect and it's composed of a capacitor which produces the electric discharge. On the high voltage part of the capacitor has a dielectric layer which can be a heat-resistant glass or quartz compound and the opposing part is the ground. So, between these parts of the capacitor, the oxygen or air will flow, as shown in Fig. 1.

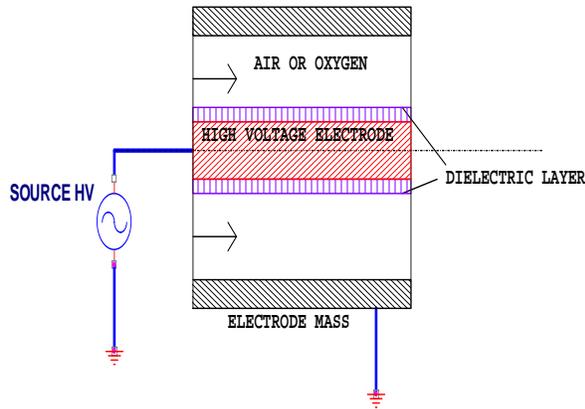


Fig. 1. Schematic diagram of the ozone generator.

At a given voltage depends on the thickness of air or oxygen, pressure and humidity, the CORONA discharge will occur, after which he generates ozone. The breakdown voltage of air layer is calculated with (3):

$$U_a = 2,86(\text{KV}) \cdot \rho \cdot d(\text{mm}) \quad (3)$$

where ρ - is the relative density of gas and d is the gas layer thickness, measured in millimeters.

On energy considerations, the efficiency of ozone production in the CORONA plasma, the following relationship must be respected:

$$p \cdot d = 2.1 \left\langle \text{atm} \cdot \text{mm} \right\rangle \quad (4)$$

p - is absolute pressure of the gas, while d - is the distance between the electrodes.

Those ozone generators which are operating at appropriated atmospheric pressure, the gas space thickness is about 2 mm, and for those who work in higher pressures the gas space thickness becomes smaller.

The dissipated electrical power in the ozone generator is calculated, with the following equation:

$$P_d = \frac{\omega}{\pi} \int_{t_0}^{\frac{\omega}{\pi} + t_0} U_a i dt \quad (5)$$

where ω - is the frequency of the AC voltage which is applied to the ozone generator, t_a - is CORONA discharge timing, while i - is the current through the generator. To calculate the dissipated electrical power in the ozone generator we must estimate his impedance under operating conditions. We will assimilate the ozone generator (generating chamber) in terms of an electrically equivalent circuit, as shown in Fig. 2.2. On this case, the current

through the ozone generator is given by the following relation:

$$i = C_{dielectric} \frac{dU_{supply}}{dt} \quad (6)$$

The concentration of ozone in the flowing gas through the ozone generator is calculated the following relation

$$c(\text{g}/\text{m}^3) = k_1 \{1 - \exp(-K_2 P_1 / Q)\} \quad (7)$$

where k_1 - is the stationary coefficient of the generator, coefficient of ozone decomposition while Q - is the flow of air or oxygen.

For the generator modeling in the production of ozone, we must obtain useful data, so we should done this by using an inverter power supply and the following steps, regardless of choice for simulation software:

Data collection - it is necessary to make the model and for these we will turn to those models which have appropriate parameters for a more accurate simulation of system operation.

Building the model - is the connection stage of all items, in which the selected software will calculate the voltages and currents of the generator.

Calibration - is the process of adjusting the input data which is required, until the output (results) reflects real values.

Analysis - is the process of analyzing and planning the tasks to which the system works, using a model already calibrated or based, which is all ready use an calibrated model.

3. Modelling the installation

The plant model consists of an inverter semi-bridge, as shown in Fig. 2, which consists of four IGBT transistors inverter connected in parallel two by two with one capacitive divider and fed with continuous voltage, which is coming from single-phase recovery voltage of 230 V, 50 Hz. At the output of the inverter, is connected the primary winding of high voltage transformer for obtaining the power of the ozone generator. Order transistors constituting the inverter (see Fig. 3) is a specialized PWM circuit (UC 2825) with two outputs in anti-phase, followed by an integrated circuit (RI 2113). Measuring current in primary winding of the transformer is made by an integrated Hall sensor (ACS 72-20A), here the measured value is taken by the implemented current regulator circuit PWM. PWM oscillation frequency of the circuit was set to 4 kHz.

Physical equipment model is presented in Fig. 4.



Fig. 4. Production Equipment modeled ozone-positioning.

4. Modeling experimental facility

For the modeling of the ozone generator and its power source we have relied on the platform MATLAB, and he's SIMULINK module in which were extracted the mathematical and physical symbols from he's library and that were set with actual component values, to simulate the real appliance, and these model presented in the Fig. 5.

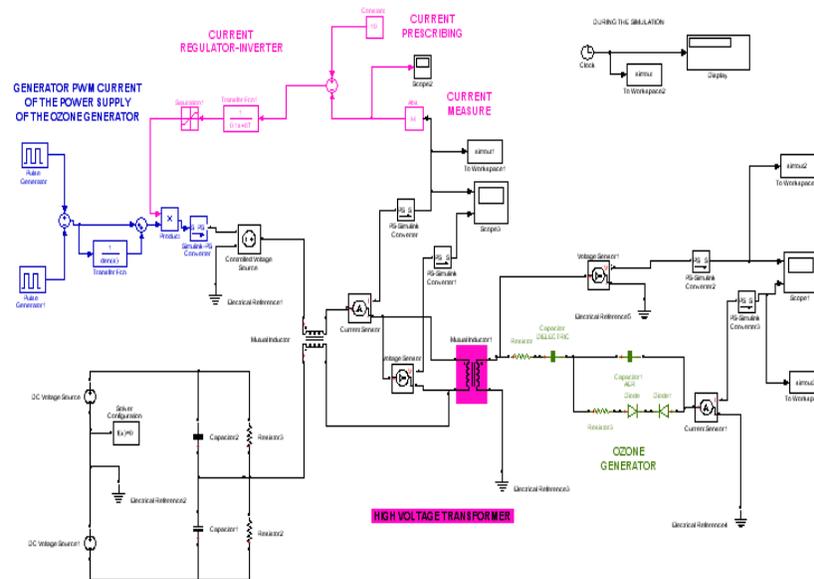


Fig. 5. The SIMULINK model of the ozone generator and its power inverter.

5. Sizing the model

Model calibration is done by setting the component values of Simulink model and run repeatedly so as to derive electrical signals calculated and displayed on the component "Scope", which does not differ by more than 5% of the measured signal on an oscilloscope at the same place in the real plant. In the model to measure voltage in any of its enclosing blocks points we will use: Voltage, Sensor, PS-Simulink, Converter and measure current with the following blocks: Current, Sensor, PS-Simulink Converter and Scope.

By running the model, the following graphs were obtained, as shown in Fig. 5:

- the power supply primary winding of the transformer with voltage increaser;
- voltage of the transformer primary;
- the transformer secondary voltage of the ozone generator used to power it up;

- current through the ozone generator.

By running the model, the resulting graphs for the power supply to the transformer primary winding high voltage of the transformer primary voltage, the transformer secondary voltage generator used to power the current ozone and ozone generator.

6. Results

To study the behavior of the model at different supply currents in the primary winding of the high voltage transformer, which has the effect of different voltages and currents through the ozone generator, the generator must be set to be controlled (PWM generator) at different filling factors. In this case we have chosen the following values: 25, 35 and 45%. The obtained values for voltages supply of the ozone generator are shown in Fig. 6, and those for currents are shown in Fig. 7.

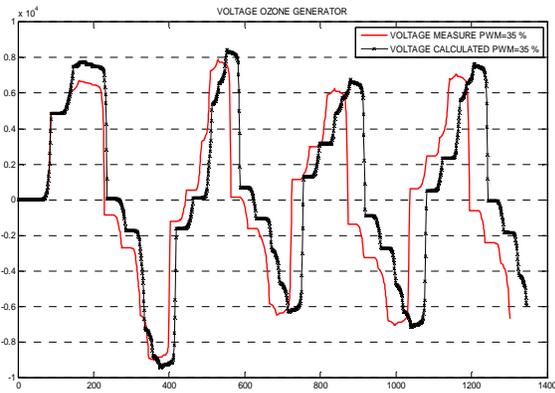


Fig. 6. The voltage of the power supply in the ozone generator for PWM=35 %. Voltage of the measured and calculated ozone generator for PWM = 35%.

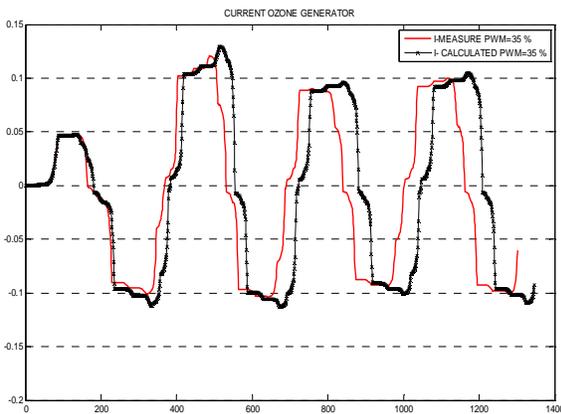


Fig. 7. The currents feeding of the ozone generator for different values of filling factor. Supply current measured and calculated ozone generator for PWM = 35%.

7. Conclusions

Using the steps of MODELING, SIMULATION AND OPTIMIZATION from the design phase of a product we can determine its performance, options to be implemented, the influence of each component, static and dynamic behavior of the whole system. MATLAB SIMULINK program module advantage over other specialized software (ORCAD, LTspice) is that its library has a lot of mathematical models, which in many case for real components or physical process (like mechanical, pneumatic, electrical, electronics, etc..) by which we can build a model for a real product.

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