ICESP X – Australia 2006
Paper 6B3

NOVEL ESP MODEL FOR IMPULSE ENERGISATION

T. IVÁNCSY[1], J.M. SUDA[2], I. KISS[1] AND I. BERTA[1]
[1] Department of Electric Power Engineering
[2] Department of Fluid Mechanics
Budapest University of Technology and Economics
Muegyetem rakpart 3. H-1111 Budapest, Hungary
ivancsy.tamas@vet.bme.hu

ABSTRACT
Recently more and more electrostatic precipitator has been upgraded, replacing the traditional DC power supply with impulse energisation. Different types of supply voltage were applied to obtain current impulses for reducing back corona, earning energy saving and better efficiency of precipitation.

For the evaluation of the effect of impulse energisation, several numerical models were made using different computational methods. A large number of models calculate ion space charge density distribution assuming continuous ionic current between high voltage and grounded electrodes. This assumption can lead to incorrect result when the "travelling time" of the ions and the time period of the supply voltage (duration of the current impulses and "current free" periods) are in the same range.

Our new model for the ion space charge density calculation takes into consideration the rapid, time dependent processes providing more reliable results for the evaluation of the precipitation process. By the help of the new model a detailed analysis of different supply modes can be carried out, to obtain the best possible operation of a given electrostatic precipitator.

INTRODUCTION

The advantages of the pulse energisation are well known for long time. To achieve better performance the modelling of the pulse energisation is vital.

At the Budapest University of Technology and Economics as a co-operation between Department of Electric Power Engineering and Department of Fluid Mechanics an ESP model was developed [Ref. 1]. This model has limited capability in modelling pulse energisation (*ms* pulses), therefore it was needed to further develop of the model to be able to model pulse energisation with *ms* pulses.

BRIEF DESCRIPTION OF OUR ESP MODEL

This model contains two main modules, one for the determination of the electric field and another one to calculate the flow field. Figure 1 illustrates the structure of the model.

The first model solves the Laplace-Poisson equation based on the integral equation method. The first term in Eq. 1 shows the effect of the space charge ρ_V, the second term describes the influence of the surface charges (ρ_A) situated on surface A_1, while the third term gives the potential value originated from the dipole moment ν on surface A_2.

$$\varphi(P) = \frac{1}{4\pi\varepsilon}\int_V \frac{\rho_V}{r} dV + \frac{1}{4\pi\varepsilon}\int_{A_1} \frac{\rho_A}{r} dA + \frac{1}{4\pi\varepsilon}\int_{A_2} \nu \,\mathrm{grad}\frac{1}{r} dA \qquad (1)$$

In our case ρ_A represents the surface charge on the corona and collecting electrode, ρ_V is the sum of the ion and particle charge density, while the third term is neglected. At the determination of the particle charge, the model takes into consideration both of the diffusion and the field charging. Regarding, that the space charge is influenced by the electric field and the electric field is influenced by the space charge, the field computation requires an iteration process. For solving Eq. 1 by iterative procedure a numerical module was constructed.

The inputs of the module are the velocity field and the concentration distribution at a given moment, the geometrical and electrical parameters of the ESP chamber and the dust properties (these data are necessary to describe the charging process [Ref. 3]). The output is the drift velocity component of the particles originating from the effect of electric field. It can be determined based on Eq. 3.

The second module determines the gas flow field and particle transport properties, i.e. the particle concentration distribution and particle velocity field. In this paper we are focused on the determination of the *c* particle concentration with the help of our previous simple particle transport model using of the convective diffusion transport equation (Eq. 2), where assumptions are used, namely, streamwise particle diffusion and streamwise component of the particle migration velocity is neglected.

$$v_x \frac{\partial c}{\partial x} + v_y \frac{\partial c}{\partial y} = \frac{\partial}{\partial y}\left(\frac{\nu_t}{Sc_t}\frac{\partial c}{\partial y}\right) - \frac{\partial}{\partial y}\left(c \cdot w_{th,y}\right) \qquad (2)$$

In the Eq. 2 the gas flow velocity components v_x and v_y, were computed by a FD scheme of boundary layer equation where turbulent viscosity u_t is evaluated on the bases of the mixing length model [Ref. 4]. Particle diffusion term in Eq. 2 is calculated based on local values of turbulent viscosity and turbulent Schmidt number (Sc_t) and $w_{th,y}$ is the theoretical drift (or migration) velocity expressed according to Eq. 3.

$$w_{th,y} = \frac{Q_p^{\infty} E_y}{3 p m d_p} Cu \,, \tag{3}$$

where Q_p^{∞} is the saturation charge of a spherical dust particle with a diameter d_p according to the Cochet's charging equation. Moreover, in Eq. 3 particle migration velocity is corrected by the Cunningham correction factor (Cu), μ is the dynamic viscosity of the fluid and E_y the transversal component of the electric field strength vector.

Eulerian approach is applied for particle transport modelling, the suspended particles in a gas stream are regarded as a continuum phase, hence particle flow can be characterized by the particle flow stream function (Y). As usual way, the motion of particles can be illustrated by the trajectories that correspond to the Y=const. lines i.e. contour lines of the particle flow stream function.

DIFICULTIES IN MODELING THE PULSE ENERGISATION

To examine the effect of the supply mode, time dependency of the processes has to be involved into the model. Usually it is made by creating a time loop to calculate physical quantities after a given time. Our steady state model that is based on the calculation process presented in the previous chapter is not suitable to calculate the effect of impulse mode supply, because it is constructed to make an iteration to obtain steady state condition, considering continuous gas flow, voltage, ionic current and incoming dust amount. Therefore the ESP model had to be improved to involve the time dependency into the model. To take time dependency into consideration we need to modify mainly the modules calculating the ion space charge and dust charging.

By calculating the ion space charge we assume that by a given supply voltage the corona current can be calculated which continuous present in the ESP's half channel. This assumption is fulfilled only when the supply voltage is constant for longer time than the ions travelling time through the half channel of the ESP.

Assuming the ion mobility constant

$$m_i = 2 \cdot 10^{-4} m^2 / Vs \tag{4}$$

and the pseudo homogenous field strength is

$$E_{ps} = 20 kV / 3cm \tag{5}$$

(in a model scale precipitator), the average travelling time of ions can be calculated based on the following estimated ion velocity calculated by Eq. 6

$$m_i \cdot E_{ps} = 2 \cdot 10^{-4} \left[m^2 / Vs \right] \cdot 2 \cdot 10^4 \cdot 3^{-1} \cdot 10^{-2} \left[V / m \right] \approx 1.3 \cdot 10^2 m / s \tag{6}$$

hence the travelling time through the 3 cm wide half channel takes about

$$t = \frac{3 \cdot 10^{-2} m}{1.3 \cdot 10^{2} m/s} = 2.3 \cdot 10^{-4} s \tag{7}$$

That means by a microsecond cycle time that the supply voltage changes so fast that a steady constant ionic current could not evolve. Should the case occur that a supply mode whit shorter pulses generates greater current pulses the discharge will change. On the corona electrode the glow-corona changes to streamer discharges. To calculate the current of the streamer discharges another model is needed than the Peek model. [Ref. 2]

A model is needed which can follow the changes in the supply voltage, and calculates the ion space charge for shorter time steps (Δt) than the period of the supply voltage.

DONOR CELL METHOD

In our new model the donor cell method is used to determine the ion space charge in the ESP half channel [Ref. 5]. The advantage of this method is the use of an irregular (non equidistant) grid division. So the focus can be on parts of the ESP channel where changes are relevant, and other parts, where physical values not much differ, can be out of focus to fasten the calculation.

The equation $divJ = 0$ is valid for each cell in the grid, so the number of charges entering a cell, equal the number of charges leaving the cell. The current density in a cell is proportional with the ion mobility in the cell (m), with the charge density in the adjacent cells (r_i) with the potential between the adjacent and the current cell $(j_j - j_i)$, and inversely proportional with the distance of the cells $(\Delta_{j,i})$ which is the distance between the midpoints of the cells.

$$J_{j,i} = r_j \cdot m \cdot \frac{j_j - j_i}{\Delta_{j,i}} \tag{8}$$

By the charges leaving the cell the charge density of the cell is taken into consideration.

$$J_{k,i} = r_i \cdot m \cdot \frac{j_i - j_k}{\Delta_{k,i}} \tag{9}$$

If we complete the equation $divJ = 0$ with the charge loss coming from the recombination of the charge carriers, we get the equation

$$J_{j,i} \cdot L_{j,i} + J_{k,i} \cdot L_{k,i} + J_{l,i} \cdot L_{l,i} + R_i \cdot A_i = 0 \tag{10}$$

where R_i means the recombination factor for the charge carriers. The solution of the linear equation system gives the ion space charge in the ESP half channel.

To follow the change of ion space charge density in time, it is necessary to modify the donor cell method into a time-dependent form [Refs. 5 and 6]. It means that instead of the balance of currents (or current densities) of the donor cell, the balance of transported charge has to be determined. For this purpose a time step *dt* is introduced, to obtain a charge amount (as a multiplication of the current and the time step) flowing into and out from the cell. With this procedure, the change of ion charge can be monitored inside the cell as a function of time.

Time step *dt* is chosen to such a value, which is significantly below the "residence time" of a charge carrier inside a specific donor cell. This requirement can be fulfilled, when the time step is less than the shortest side of the donor cell (*ds*) divided by the product of ionic mobility (*m*) and electric field strength (*E*):

$$dt << ds / (m E) \tag{11}$$

The previously described method requires the modification of the process of calculation as well as the data structure of the model. A new set of data has to be added to the existing data structure storing the initial ionic charge density

i) calculation of the electric field with the initial ionic charge density
ii) calculation of currents according to the donor cell method
iii) determination of charge transfer during time interval dt using the initial ion charge density values
iv) calculation of actual ionic charge density
v) replacing initial ionic charge density by the new one and going back to step 1.

As an illustrative example a simplified calculation method is presented in the following figures. Simplified means, that corona electrode is handled as a wire, therefore the change of current density along its surface is not taken into consideration. Figure 2 represents the moment, when supply voltage exceeds corona level (*U=20kV*) and the charge carriers starts to drift towards the grounded electrode. Figure 3 shows that situation, when steady state ionic current could be formed. Values fit well to the result of the steady state model. Finally, in Fig. 4 moment of reducing supply voltage below the corona limit (*U=10kV*) is shown.

REFERENCES

[1] Iváncsy, T., Kiss, I., Suda, J.M. & Berta, I. (2004) Efficiency of the precipitation of fine particles influenced by the ESP supply mode. *Proc. IX. Int. Conf. Electrostatic Precipitation*, Kruger Gate, South Africa, 2004, Paper No. A01.

[2] Gallimberti, I. (1997) Recent advancements in the physical modelling of electrostatic precipitators. *Proc. 8th Int. Conf. Electrostatics*. Poitiers, France, 1997.

[3] Chang, J.S. (1995) *Electrostatic charging of particles. Handbook of electrostatic processes.* Marcel Dekker, New York, 1995. pp. 39-49 (Chapter 3).

[4] Masuda, S. & Hosokawa, S.(1995) *Electrostatic precipitation. Handbook of electrostatic processes*, Marcel Dekker, New York, 1995. pp. 441-479 (Chapter21).

[5] Meroth, A.M., Gerber, T., Munz, C.D. & Schwab, A.J. (1996) A model of the non-stationary charge flow in an electrostatic precipitator. *Proc. VI Int. Conf. Electrostatic Precipitation*, Budapest, Hungary, 1996, pp 130-136

[6] Meroth, A.M., Nicolaus, S., Levin, P.L. & Schwab, A.J. (1996) Effective solution of 3D charge coupled problems in electrostatic precipitators. *Proc.VI Int. Conf. Electrostatic Precipitation*, Budapest, Hungary, 1996, pp 137-143.

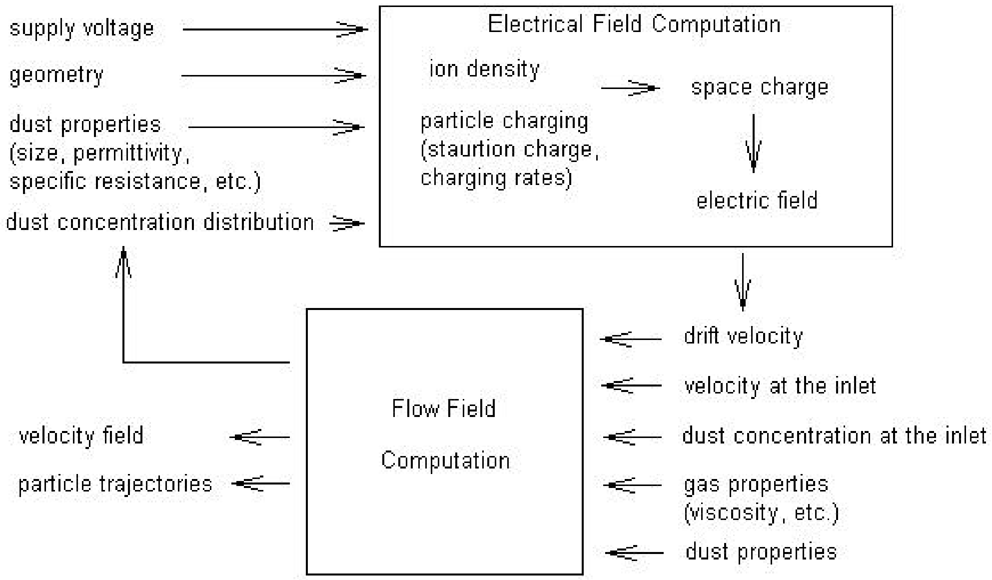

Figure 1: Diagram of the numerical model

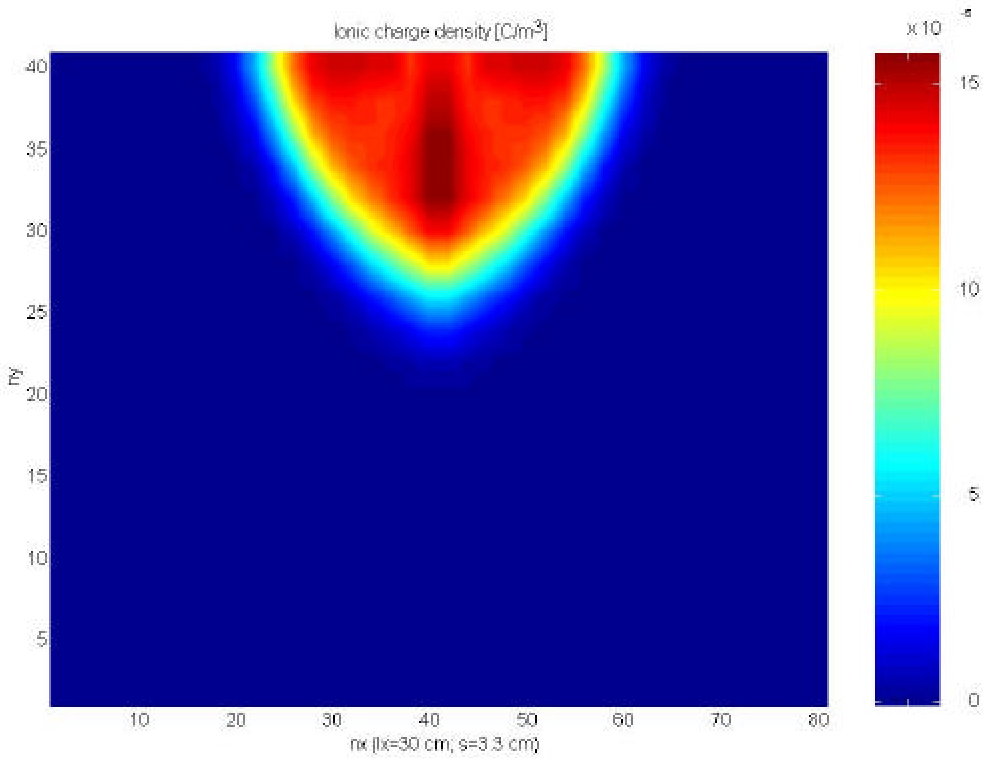

Figure 2: Ionic space charge density just at the appearance of 20kV supply voltage

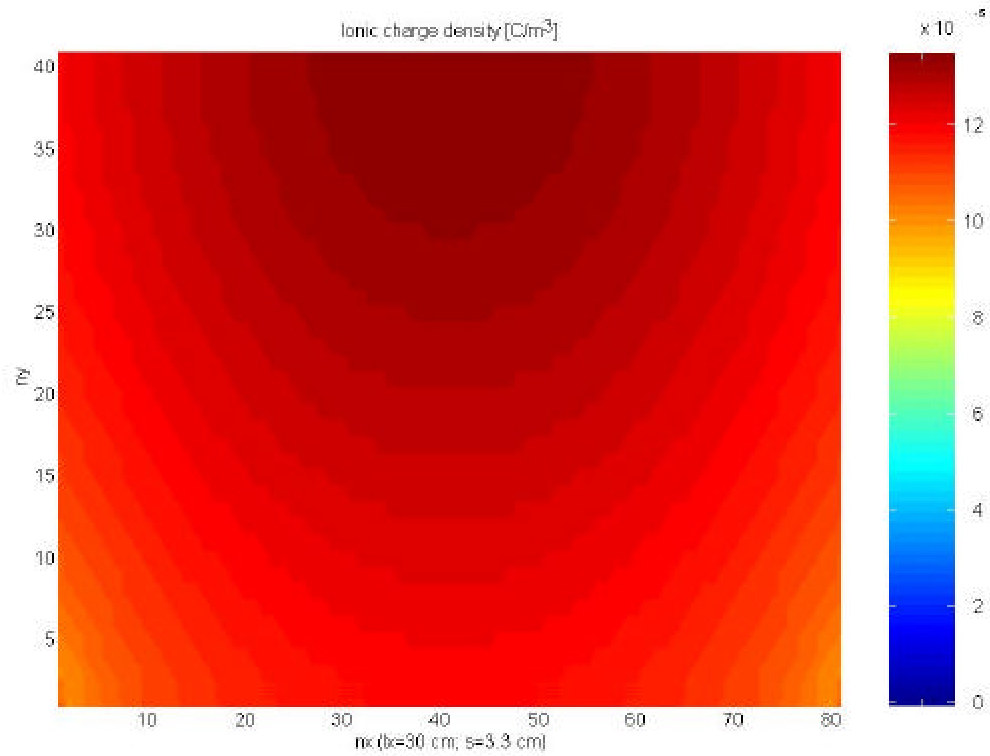

Figure 3: Ionic space charge density at continuous corona current

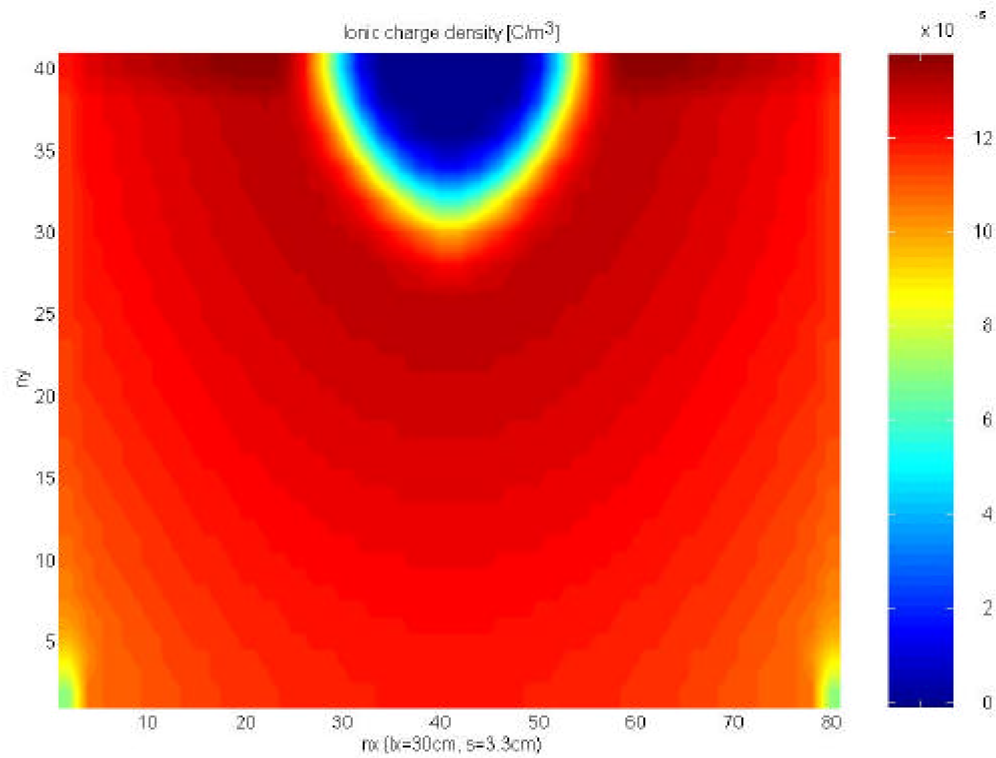

Figure 4: Ionic space charge density just after the appearance of 10kV supply voltage