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MACHINE LEARNING APPROACH FOR ELECTRIC ARC DISCHARGE PARAMETERS ESTIMATION

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Abstract
This article presents a machine learning approach for electric arc discharge parameters estimation. The machine learning approach is implemented on multilayer convolutional neural network trained over a video stream of electric arc discharge in visible light spectrum. A convolutional neural network architecture performance is evaluated to estimate the efficiency in that particular application. The measured parameters of the electric discharge process are used in dedicated virtual instrument through which all needed dynamic and steady-state characteristics are calculated in real time and compared with predicted neural network results.

Keywords: machine learning, convolutional neural network, electric arc discharge.

INTRODUCTION

Many physical systems cause problems for which the artificial neural networks (ANN) can be successfully applied [1–9]. Real world tasks lead to inverse problems which in most cases are ill-posed. If a standard ANN approach is applied to such inverse problems in a straightforward manner, the model will either converge approximating the target data and representing their average value, or will not converge in some cases of infinite number of output values for each input. These approaches frequently provide very poor performance, since the average of the possible solutions is not necessarily itself a solution. The ANNs could be applied as a fast unstructured approach with low computational cost in numerical field analysis both for classification and pattern recognition. At present ANNs are well developed and documented techniques for a wide range of image processing applications. Also ANNs are used for image building, corresponding to training data sets with hierarchical structures between the building elements. [3-7]

This article presents a machine learning approach for electric arc discharge parameters estimation. The machine learning approach is implemented on multilayer convolutional neural network trained over a video stream of electric arc discharge in visible light spectrum. A convolutional neural network architecture is evaluated in order to estimate the efficiency in that particular application. The process observations are performed by experimental setup associated with DAQ (Data Acquisition) device and a personal computer. Software package LabVIEW is used together with required drivers for data acquisition devices. The measured parameters of the discharge process are used in dedicated virtual instrument through which all needed dynamic and steady-state characteristics are calculated in real time and compared with predicted neural network results.

CNN ARCHITECTURE

In the field of Machine Learning (ML), the Convolutional Neural Networks (CNN) are a class of deep, feed-forward artificial neural networks that has been applied successfully to analyzing image data. They could be applied as a fast unstructured approach with low computational cost in numerical field analysis both for forward and inverse problems. At the present CNN are well developed and documented techniques for wide range of image processing techniques. Also CNN are used for image building corresponding to training data sets. [1-4]

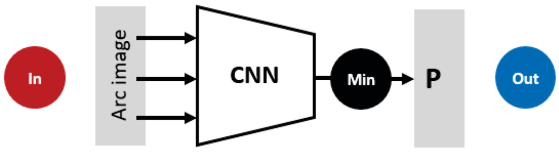

Fig. 1. *CNN architecture.*

CNN are organized as a typical radial basis function neural network where data size is reduced on each next network layer. Convergence is based on stepwise local filtering and aggregation with defined pooling function. They are especially used for image recognition and object classification applications on pixelated image data [2], [3]. In the proposed approach CNN architecture (Fig.1) uses a multi-layered input image of an electric arc discharge.

CNN architecture uses one convolutional flow with multilayer filter 3 × 3 pixels with stride steep 1 and convolution steep -1. Laplace operator is used for pooling function. Convolution function is presented on (1),

$$\mathbf{X}_j = \sum_{i=1}^{n} \nabla w_{(i-c)(j-c)} \mathbf{X}_i , \qquad (1)$$

where $\mathbf{X}_i$, $\mathbf{X}_j$ are the vectors of the input and output layers respectively, over n-sized filter, with convolution descent c, by the gradient of weighted coefficients w_{ij}. At the presented architecture filter size is 3×3 (i=9), which is forming 2×2 matrix of weighted gradients and output vector X_j is with 2×2 size (j=4) in c = -1 convolution step.

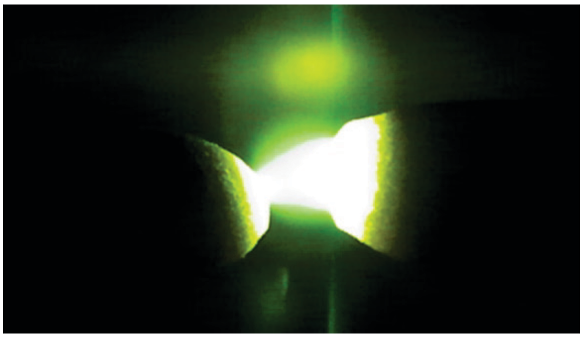

Fig. 2. *UV filtered optical picture of arc discharge between round tips of two graphite electrodes, arc length as electrode distance is set to 3 mm.*

ELECTRIC DISCHARGE TESTING

All presented data are directly measured by real-time data acquisition system with sampling rate up to 50 kS/s. Results are representing steady-state discharge, where electric results are acquired at the 1st second after ignition and contains 6 full 50 Hz periods or complete of 120 ms of voltage and current data. Acoustic results are recorder at arc discharge ignition and have a duration of 3 s after the beginning.

UV filtered optical picture arc discharge between round tips of two graphite electrodes, arc length as electrode distance is set to 3 mm.

Main harmonics are compressed and approved for data collection of the sensing node on every 20 s.

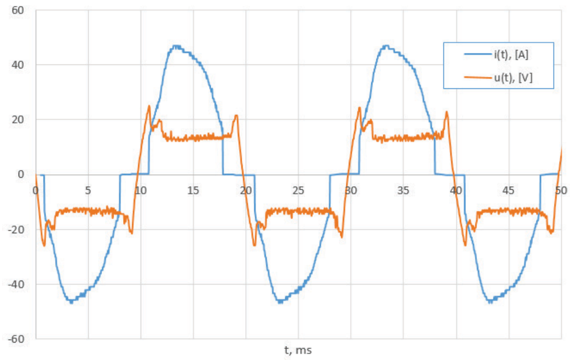

Fig. 3. *AC arc discharge current and voltage oscilograms.*

AC arc discharge current and voltage oscilograms are presented in Fig.3. RMS integrated current are around 22.3 A at voltage of 18 V. Corresponding electric power is 400 W. Arc length is 3 mm. Load inductance is negligible.

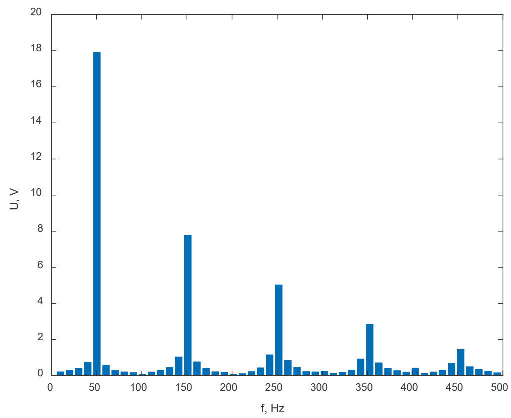

Fig. 4. *Arc discharge voltage harmonic spectrum content.*

Arc voltage harmonic spectrum content obtained by FFT at 10 Hz steps is presented in Fig.4. Main harmonics are 3rd, 5th, 7th, etc. Which are coming from ignition time interruptions and power supply transformer nonlinearities. These data could be filtered with the no-arc voltages harmonics which are not related with arc discharge voltage.

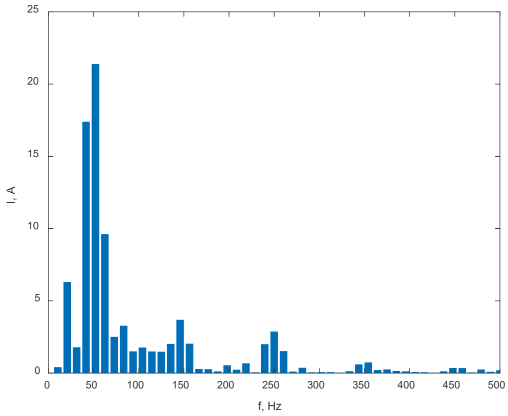

Fig. 5. *Arc discharge current harmonic spectrum content.*

Arc current harmonic spectrum content obtained by FFT at 10 Hz steps is presented in Fig.5. There is a relatively huge harmonic distortion below 250 Hz, most of it below 150 Hz.

Electric parameters presentation is limited to 500 Hz, after harmonic amplitudes are becoming negligible compared to first main harmonic.

AC arc discharge electric power is presented in Fig.6. No-arc time periods with zero current are visible. Peak arc power is reaching 600 W or 400 W continues power estimated by rms values of main harmonic.

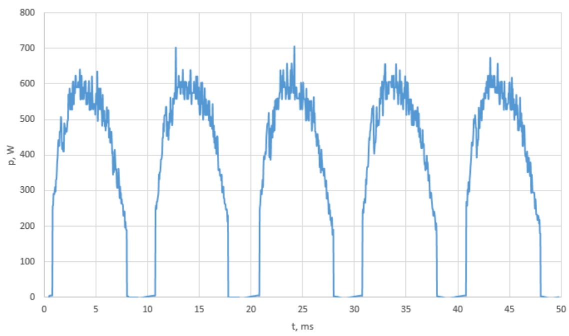

Fig. 6. *AC arc discharge dynamic electric power.*

Electric power harmonic spectrum content obtained by FFT at 10 Hz steps is presented in Fig.7 and Fig.8. Power spectrums are separated into two frequency ranges, first up to 600 Hz and second from 600 Hz to 2000 Hz. Discharge power has doubled the current and voltage harmonics. So peak frequencies at doubled i.e. 50 Hz, 100 Hz, 150 Hz are observable as 100 Hz, 200 Hz, 300 Hz. In second range, from 600 Hz to 2000 Hz, amplitudes are reduced nearly 20 times, but significant groups are easily detected around 800 Hz, 1200 Hz, 1600 Hz and 2000 Hz. In Fig.8, FFT is performed again at 10 Hz bin, where at 100 Hz bins groups will be boldly groped and interconnected.

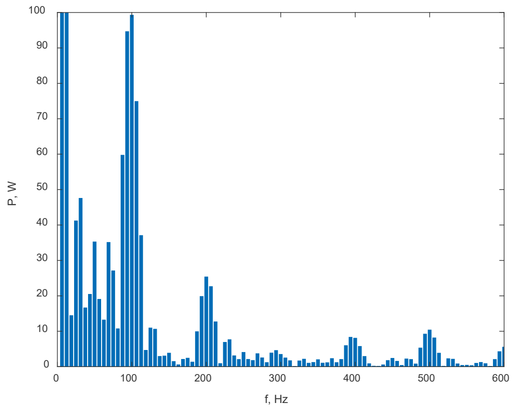

Fig. 7. *AC arc discharge dynamic electric power.*

Electric power arch discharge spectrums are separated into two frequency ranges, first up to 600 Hz (Fig.7) and second from 600 Hz to 2000 Hz (Fig.8). Measured AC electric arc discharge acoustic power spectrum from 1 Hz to 2000 Hz is presented in Fig.9. Electric results as power, voltage and current, have been acquired at the 1st second after ignition and contains 6 full 50 Hz periods or complete of 120 ms of voltage and current data. Acoustic results are recorder at arc discharge ignition and have a duration of 3 s after the beginning. Fig.9 spectrum is integrated for 3 s interval of acoustic power in dBm.

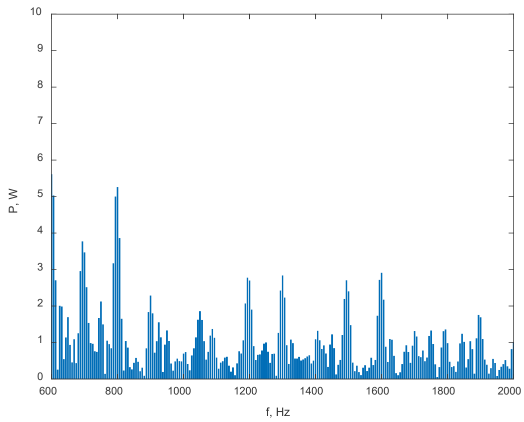

Fig. 8. *Electric power harmonic spectrum from 600 Hz to 2000 Hz.*

Frequency and time samplings of electric and acoustic spectrums are different. Electric sampling is 50 kS/s, for 120 ms series, with 10 Hz bins in spectrograms. Acoustic sampling is 44 kHz, at 100 ms sample groups, with 50 Hz spectrum bins.

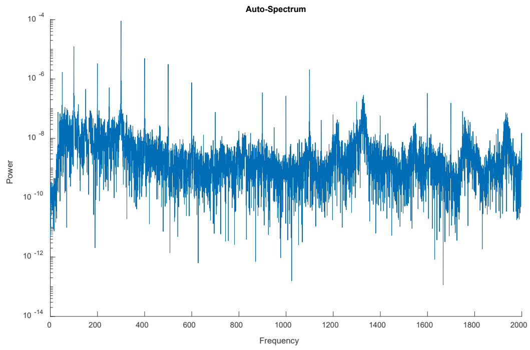

Fig. 9. *AC electric arc discharge acoustic power from 1 Hz to 2000 Hz.*

Frequency and time samplings of electric and acoustic spectrums are different. Electric sampling is 50 kS/s, for 120 ms series, with 10 Hz bins in spectrograms. Acoustic sampling is 44 kHz, at 100 ms sample groups, with 50 Hz spectrum bins.

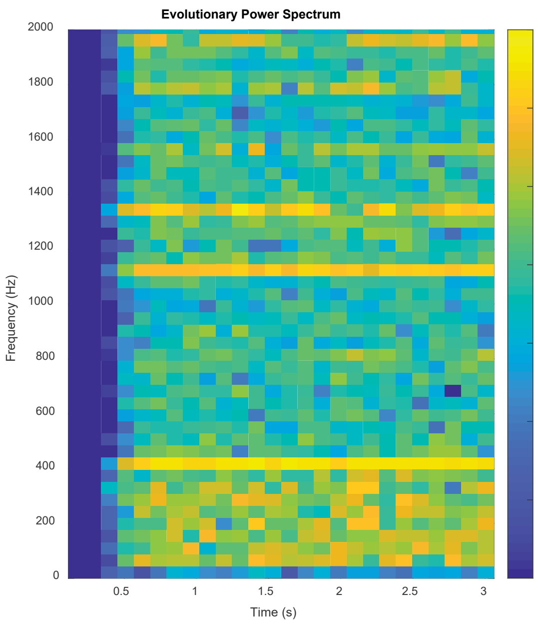

Fig. 10. *AC electric arc discharge acoustic power amplitude (dBm), for frequency range from 1 Hz to 2000 Hz, at 0 to 3 s time series.*

There is a good agreement between electric power spectrum and acoustic power spectrum of the AC arc discharge. Correlation is good for electric power spectrum to acoustic power spectrum, but not for current and voltage repeatability frequencies. These means that discharge acoustic spectrum is related mainly with pressure fluctuations, temperature fluctuations, volumetric ionization and other important effects, that could be detected by acoustic spectrum measurements as an indirect electrically decoupled source of information for diagnostic and monitoring systems of LV and HV electrical equipment.

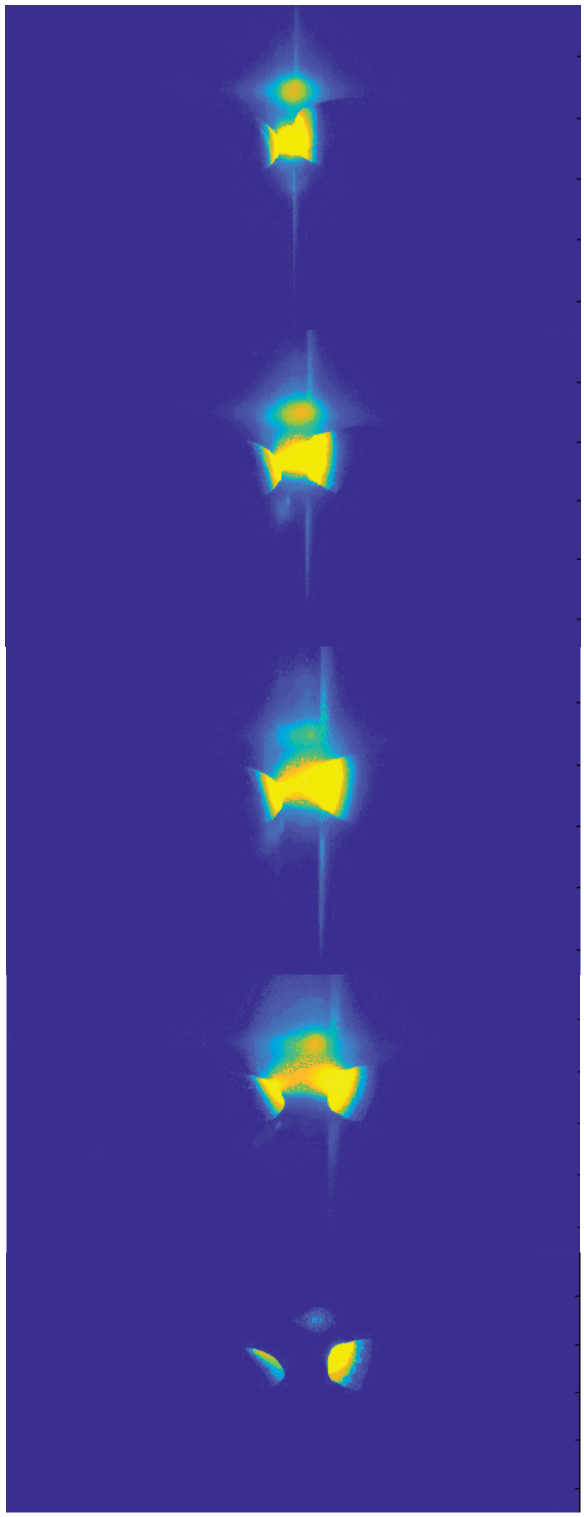

Fig. 11. *AC electric arc discharge image data.*

CONCLUSION

Measurements of atmospheric pressure AC electric arc discharge by visual image processing by CNN have been performed. Electric parameters of discharge are recorder simultaneously. Correlation of visual image data spectrum to electric voltage, current and power has been estimated. Analysis of harmonic spectrums by FFT of electric and visual image discharge dynamic parameters has been performed. Overlapping of electric and visual results is presented in the frequency domain. There is a good agreement between electric power spectrum and visual image spectrum of the AC arc discharge.

ACKNOWLEDGMENT

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