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Process Simulation in the AC Welding Arc Circuit Using a Cassie-Mayr Hybrid Model

Simulated process characteristics were compared with those found experimentally to validate the hybrid model

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ABSTRACT

This paper presents the results of experimental studies of an AC welding arc. Using the genetic algorithm, the schedule parameters of a Cassie-Mayr hybrid model were calculated over a wide range of welding transformer settings. A hybrid arc macromodel was created in the Matlab-Simulink program. Simulation of processes was done in the arc circuit. Obtained arc characteristic families were compared with those found experimentally, confirming the usefulness of the hybrid model to simulate processes in the welding arc circuit.

Introduction

The electrical properties study of an alternating current (AC) welding arc is a result of the growing need to improve the design and to optimize the parameters of mass-produced and operated welding transformers. It is also important for the better understanding of harmful effects of transformers, which are loaded to electricity grids and other power consumers. Among the many simplified mathematical models of the electric arc, the most common are the Mayr and Cassie models. In the case of low-current welding, the preferred is the Mayr model, and in cases of large current, a Cassie model. Since those models are very approximate, despite the theoretical criteria development (Ref. 1), determining the exact limit split of those choices is very difficult and gives ambiguous results. Additionally, a significant simplification of the nonlinear dynamic characteristics of voltage-current-carrying capacity is equivalent to omitting important physical effects in the arc, where the impact on technological processes and the electrical network can be very strong, especially in the case of resonance effects.

In contrast to switching (fading) arcs, the welding arc belongs to a class of electric stabilized arcs. However, it is usually strongly disturbed by the impact of external magnetic fields, gas flows, and rapidly preceded chemical reactions, which cause metal and slag splashes, and finally, drip passage of expendable electrode materials to the weld.

External factors (those easy and difficult to identify) affect the arc stability and the repeatability of experimental results. In comparison with an arc between graphite electrodes, an arc between a coated electrode and steel is much more excited and strongly disturbed (Ref. 2). The accompanying effects of metal oxidation and the drip passage of the molten metal to the weld disturb the experimental tests and theoretical analysis.

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Experimental Test of Welding Arc

Analyzed were the welding arc that melted an ES18-8-2 electrode and the pool formed from the previously remelted metal on a graphite substrate. The power system was a welding transformer-type STB250. Nominal parameters of the transformer are as follows: supply voltage 400 V, 50-Hz network frequency, and a maximum welding current of 250 A. The manufacturer of the device was Bester by The Lincoln Electric Co.

KEYWORDS

Welding Arc
Cassie-Mayr Hybrid Model
Genetic Algorithm
AC Current
Welding Transformers

Registration was done by a computer equipped with a measurement card and measuring transducers with opto-isolation. Previously, the welding transformer parameters were set on the basis of the short-circuit tests and the idle state with the different welding current settings. They included only those parameters that were necessary to map the simplified welding transformer schema, provided for in the Matlab-Simulink program. The experimental procedure was similar to that reported in the literature concerning the examination of transformers. Due to the large reactance's dispersion, short-circuit tests can be done with the full input voltage from a rigid network. The results are given in Table 1.

Recorded welding current runs were spectrum analyzed. The results are shown in Fig. 1. In the case of small current values, significant even harmonic values (second) were observed. This shows a slight asymmetry of the dynamic arc characteristics. The increase in the setting currents causes not only the harmonic amplitude reduction, but also reduces the influence of other harmonic odds. This means a weakening of dynamic arc characteristics linearity.

The recorded measurement data allowed mapping the hysteresis arc loop, corresponding to different current transformer setpoints. The disclosure of a short-term pitch of ignition arc voltage value was strongly influenced by the sampling frequency. But in our case, it was not large and amounted to 2000 Hz. As shown in Fig. 1, with the weak currents, only the third harmonic of the arc current may have a significant impact on the supply network. Effect of other higher harmonics is negligible, and increases with increasing welding current.

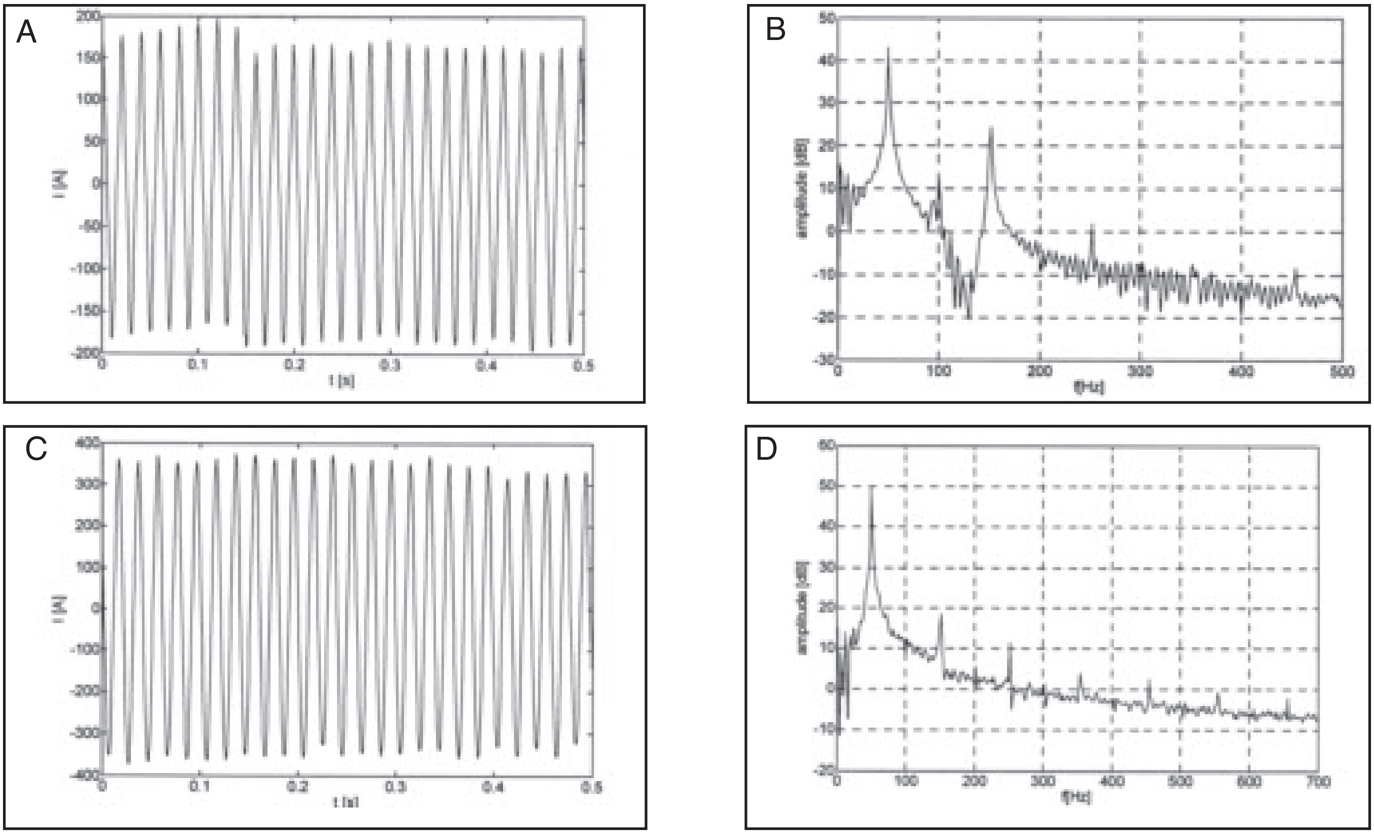

Fig. 1 — A spectogram for timing and welding current. The spectrums shown are for arc welding currents with settings: A and B — 100 A; C and D — 250 A.

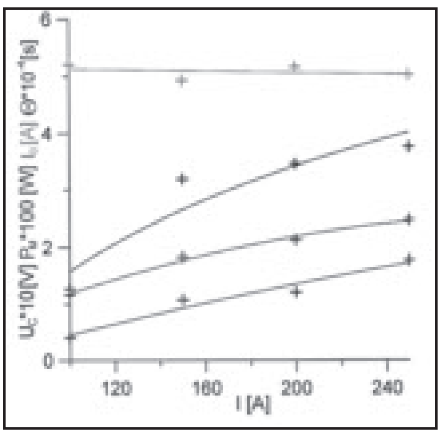

Fig. 2 — Depending on the hybrid model parameters from the welding current, the approximate functions of those charts have the following form: U_C (blue) = the logarithmic function U_C=2.66log(I)–10.66; P_M (red) = polynominal function 2nd degree P_M= –0.04I²+0.31I+1.9; I_0 (green) = the linear function I_0=–0.68e-3I+5.2; (purple) = polynominal function 2nd degree Θ= –0.015I²+0.32I+1.12.

Welding Arc Hybrid Model

Different current ranges in the applicable dynamic Mayr and Cassie models hinder the proper mapping of AC circuit runs in a great number of welding equipment. Wide ranges of current changes and different electrodes' thermal states cause the dynamic characteristics to encompass both steep and gently sloping static characteristics sections. In this case, both the Mayr and Cassie models are not able to correctly map the welding arc current and voltage runs. In this paper (Ref. 4), we suggest, therefore, automatic switching between the two models.

$$g = \frac{ui}{U_C^2} - \theta\frac{dg}{dt}, \text{ if } i > I_0 \quad (1)$$

$$g = \frac{i^2}{P_M} - \theta\frac{dg}{dt}, \text{ if } i < I_0 \quad (2)$$

where g = conductance of the arc, I_0 = limiting current, U_C = Cassie voltage model, P_M = Mayr power model, θ = time constant of the hybrid model.

The transition factor is function $\sigma(i)$ performing the dependence

$$g = \left[1-\sigma(i)\right] g_C + \sigma(i)\, g_M \quad (3)$$

the values g_C and g_M are given respectively by formulas 1 and 2. Function $\sigma(i)$ performs the dependence

$$\sigma = \exp\left(-\frac{i^2}{I_0^2}\right) \quad (4)$$

on this basis, we determined a Cassie–Mayr hybrid model in the form

$$g = G_{\min} + \left[1-\exp\left(-\frac{i^2}{I_0^2}\right)\right]\frac{u_a i}{U_C^2} - \left[\exp\left(-\frac{i^2}{I_0^2}\right)\right]\frac{i^2}{P_m} - \theta\frac{dg}{dt} \quad (5)$$

where G_{min} = constant value dependent on the distance between the electrodes, shape and placement of electrodes, gas type, and temperature of the environment in noncurrent intervals; and I_0 = transition current between the Cassie and Mayr models. In general, the attenuation function θ depends on the current i

Table 1 — Selected Parameters of the Welding Transformer with Different Settings for the Welding Current

Schema parameters	100 A	250 A
R_1 [Ω]	0.38	0.38
R_2 [Ω]	0.055	0.055
L_1 [H]	0.0234	0.0113
L_2 [H]	6.5126e-4	3.63e-4
R_{Fe} [Ω]	330.5186	346.3892
$L\mu$ [H]	0.2020	0.1875

Note: R_1, R_2 = primary and secondary winding resistances; L_1, L_2 = inductance of the primary and secondary dispersion stream; R_{Fe}, L_μ = resistance and inductance of parallel branches.

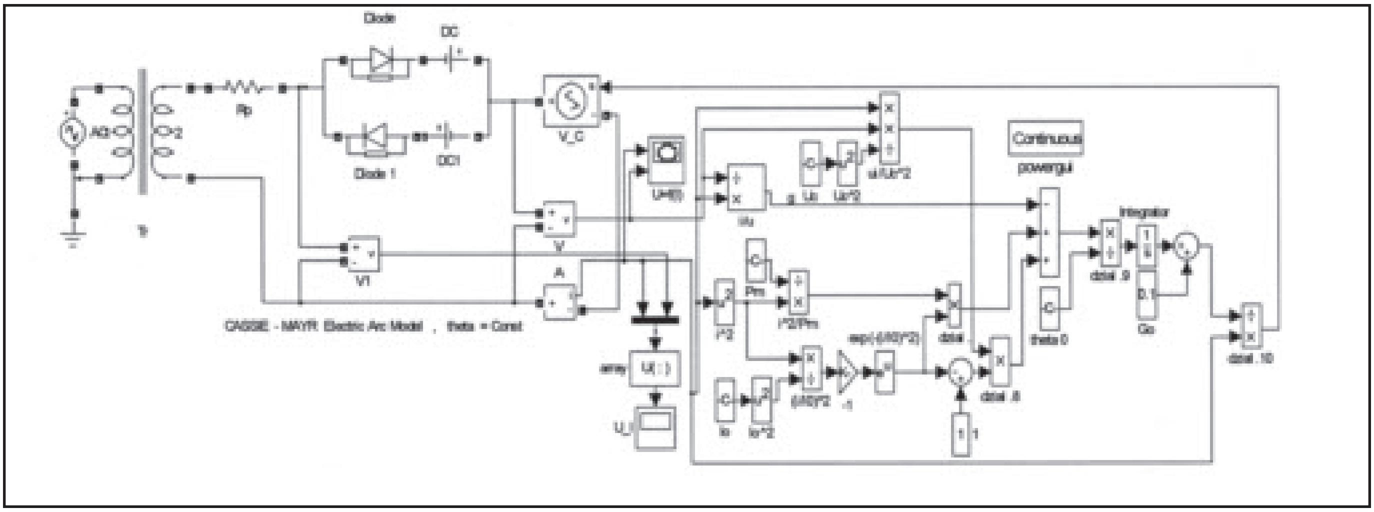

Fig. 3 — Diagram of the welding transformer, which supplies the hybrid Cassie-Mayr arc model.

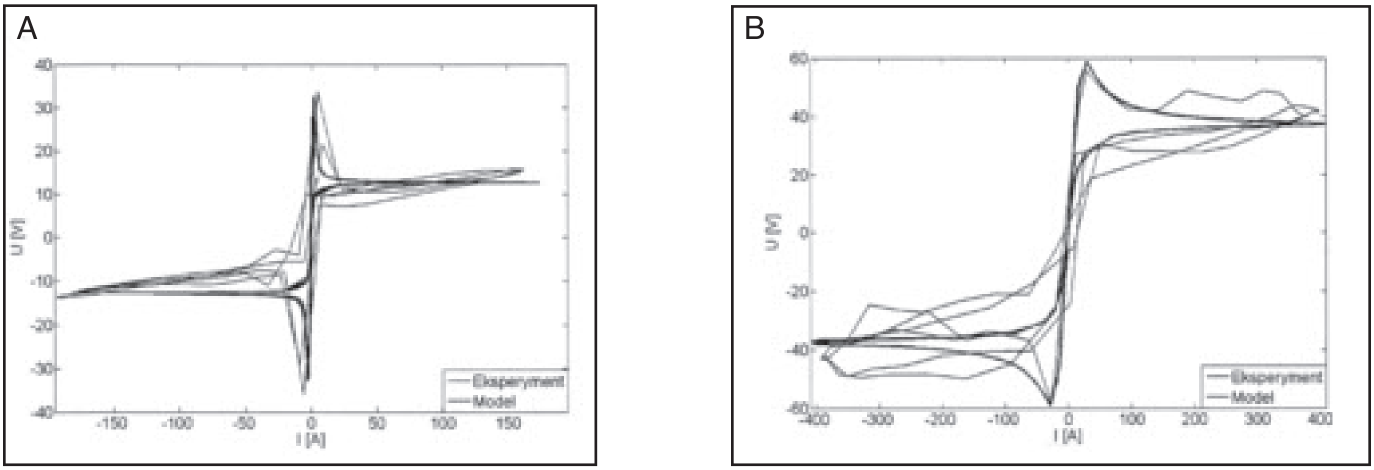

Fig. 4 — Experimental hysteresis loops of the arc and a hybrid model, taking into account the electrode's voltage drop corresponding to different current settings. A — 100 A (α =18 V, U_C = 12.74 V, P_M = 117.31 W, Θ = 0.41e-4 s, I_0 = 5.21 A); B — 250 A (α = 24 V, U_C = 37.52 V, P_M = 247.18 W, Θ = 1.77e-4 s, I_0 = 5.02 A).

$$\theta = \theta_0 = \theta_1 \exp\left(-\alpha\left|i\right|\right) \qquad (6)$$

At the same time, if the current is relatively large, it can be assumed that $\theta \approx \theta_0$, as described here.

Based on the analysis and experimental studies (Refs. 2–4), it was assumed G_{min} = 0 S and θ = constant. A genetic algorithm was used to determine the parameter of the model. The roulette method was used here, which is contained in the "gaot" library of the Matlab program. In the case with a current setting of 100 A, the following limits were assumed: U_C = (10:15), P_M = (100: 400), I_0 = (4: 6), Θ = (0.1e-4: 4e-4). If the current setting was 250 A, new tension limits U_C (15:40) were assumed.

The results of calculations are shown in Fig. 2. Almost all parameter values increased as arc current increased.

Equation 5 was used to build the hybrid Cassie-Mayr macro model, which was connected into the circuit powered by a single welding transformer — Fig. 3. The sum value of the electrode's voltage drop α was experimentally determined during the gradient determination of the tension curve (U_a = α + βL), where U_a = voltage curve, and L = length of arc. In our measurements, α ranged from 18 to 24 V.

Simulation results and physics experiments are shown in Fig. 4. Obtained arc shapes are very close to those experimentally obtained. The hybrid model provides a clear disclosure of both effects: arc ignition and voltage stabilization on the developed discharge plasma column. A small amount of limiting current of about 5 A provides a strong preference to choose the Cassie model to analyze the energy states in welding arc circuits and Mayr model for analysis of electromagnetic compatibility. Compared with those models, the advantage of the hybrid model is

Table 2 — These Are Values of Content's Coefficient of Harmonic Current Arc, Corresponding to the Different Transformer Settings

Current setpoint	100 A	150 A	200 A	250 A
THD experiment	0.1499	0.1423	0.08719	0.07417
THD simulation	0.08089	0.07609	0.0716	0.06432

its universality, keeping the simple interpretation of the basic energy effects.

The value of harmonic current arc coefficient was calculated from a quantitative comparison of experimental tests results and simulations of the model operation. The data are shown in Table 2. We can see from the figures that with the increase of welding current the value of THD decreased. This demonstrates the weakening of the nonlinear dynamic arc characteristics, caused by higher intensity of thermal processes on the electrodes and the plasma column. The discrepancies between the dates obtained from the experiment and simulation decrease with the increase of power indicates that the hybrid model correctly maps the arc behavior for the increased current value.

Conclusions

1) Cassie-Mayr hybrid model sufficiently maps the welding arc voltage-current characteristics over the whole current range.

2) The genetic algorithm is characterized by a high reliability of optimized arc parameters because it takes into consideration a wide range of measurement data.

3) A relatively small limiting current value (approximately 5 A) was determined, supporting the choice of the Cassie model to simulate the energy process for an AC welding arc. However, a relatively complete mapping of electromagnetic effects in an AC welding arc can be provided by a Cassie-Mayr hybrid model.

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