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E. Calderon, P. Schweitzer, Christophe Bonnet, Serge Weber. Influence of Perturbations Produced by Electromagnetic Interference (EMI) in Arc Fault Detection. 2018 IEEE Holm Conference on Electrical Contacts, Oct 2018, Albuquerque, France. pp.323-328, 10.1109/HOLM.2018.8611718 . hal-02065612

HAL Id: hal-02065612

<https://hal.univ-lorraine.fr/hal-02065612>

Submitted on 12 Mar 2019

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Influence of perturbations produced by Electromagnetic Interference (EMI) in arc fault detection

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Abstract—Our work focuses on the development of a test procedure and the creation of a database of current signature in presence of electromagnetic interference (EMI). These signals can affect the reliability of detection algorithms producing false tripping; therefore increasing the number of false detections. An experimental test bench allows generating series arc faults for different load configurations (UL 1699 and IEC 62606 standards). EMI disturbances are produced by the EMTEST UCS500 M4 generator.

All tests are performed with conventional household appliances (halogen lamp, vacuum cleaner, drill or computer). We rely on the EN 61000-4-4, EN 61000-4-5 and EN 61000-4-11 standards to emulate the main EMI disturbances presented in a home electrical network (lightning-type overcurrent, voltage variations, motor starts, etc.). Spectral analysis of these signals shows that EMI and the series arc spectra are comparable and can disrupt the operation of conventional detection algorithms generating considerable false detections

I. INTRODUCTION

The prevention of fires in domestic electrical installations particularly related to the appearance of an electric arc is provided by an AFCI [1]. In order to be as effective as possible, the detection rate in face to series arcs must be as high as possible while minimizing the rate of false detections. The tests to be carried out to develop an AFCI circuit breaker are described in the UL 1699 standard for USA [2] and the IEC 62606 standard for Europe [3]. Generally the detection in an AFCI is based on the analysis of the current or the line voltage of the circuit to be protected. Some authors [4] analyzed EMI/RFI (radiofrequency interference) generated by industrial systems and compared EMI intensities to those with series arc faults in the frequency band below 1MHz. In this work, we focus our attention on situations that may lead to false detections and more precisely to electromagnetic disturbances in home electrical networks. The authors have observed that a growing number of household electronic products generate electromagnetic interference capable of perturbing the proper function of common arc-fault circuit interrupter devices.

The main EMI disturbances that can be generated as well as the associated domestic loads are presented in the second part. We also present in the third part, the tests defined by EN 61000 (4-4; 4-5; 4-11) standards [5]-[7] focusing on fast transient waves (BURSTS), surge, voltage dips and variations. In the fourth part, we analyze EMI perturbations in time and frequency domain and compare them with arc faults. Given that most AFCI devices operate at frequencies below 500 kHz and exhibit a narrow bandwidth, the frequency analysis we performed was restricted to that similar frequency range. We employed a current probe with a sampling frequency of 1 MHz for the collection of this data.

II. EMI PERTURBATIONS AND EXPERIMENTAL SETUP

In the context of this paper, a perturbation is defined as an undesirable electrical disturbance able to degrade or disrupt the normal operation of a household electrical device. The origin and nature of such perturbations is broad, but all of them tend to fall into two general categories: conducted interference and radiated interference. The conducted perturbations use conductive materials as propagation paths, such as power cables for example. The radiated perturbations are transmitted by an electromagnetic wave through dielectric materials.

Most household electrical appliances are considered source of EMI perturbations. Conducted perturbations are injected directly or indirectly into a conventional home electrical network [8]-[12]. The classification of EMI perturbations is done taking into account the power operation of appliances and can be classified in two types as was done in [13]:

EMI sources due to industrial and commercial equipments

- Air conditioning
- Computer and switching circuits
- Fluorescent lamps

EMI sources due to consumer devices

- Refrigerators / freezers
- Mixers
- Washing machines
- Vacuum cleaner
- Light dimmers

All these equipments produce also electrical and magnetic radiated emissions. TABLE I gives the electric and magnetic densities levels at 30 cm from 115 Volt home electrical appliances [14].

TABLE I
ELECTRIC AND MAGNETIC DENSITIES.

Appliances	E (V/m)	B (mT)
Boiler	130	0.15 – 0.5
Refrigerator	60	2 – 20
Hair dryer	40	0.08 – 9
Vacuum cleaner	16	3.5 - 30

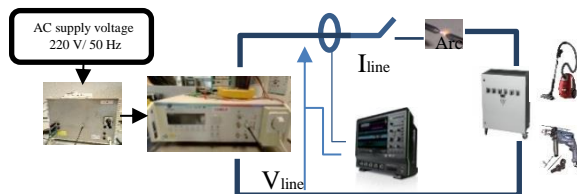


Figure 1. Experimental test bench.

In this paper, we focus only on conducted perturbations because arc fault detection algorithms in conventional AFCI

deal mainly with the analysis of the current line. EMI perturbations are obtained using an experimental test bench shown in Fig. 1.

The test bench emulates a home electrical network into which EMI may be intentionally introduced via the EMTEST UCS500 M4 generator. The current and voltage of the line are measured at the output of the generator. The characteristics of the current and voltage probes are given in TABLE II. Data acquisition is carried out by a Lecroy oscilloscope wavepro 950 (1GHz) at 1MHz sample rate.

TABLE II.
PROBES CHARACTERISTICS.

Voltage probe	Current probe
Lecroy PPe 20kV	Lecroy AP015
100 MHz BW	DC 50MHz
Max. peak 20kV	Max. peak 50A

Series arc faults are inserted in the line in simple and masking configurations (Fig. 2) according to the UL 1699 and IEC 62606 standards. For arc fault generation through opening contacts, two copper electrodes of 6mm in diameter are used for different tests.

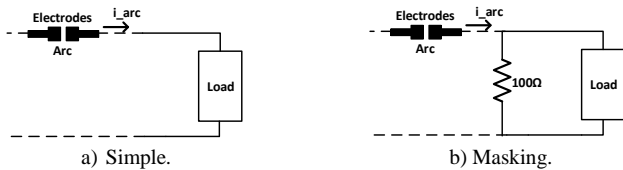


Fig. 2. Load configurations.

III. STANDARDIZED EMC TESTS

EMC standards are used for product certification. These standards specify test methods and parameters to prove the immunity of an equipment or system in face to EMI perturbations.

We will generate EMI perturbations using the EN 61000-4-4, EN 61000-4-5 and EN 61000-4-11 standards which are detailed in the following subsections.

A. EN 61000-4-4 standard-Fast transient immunity (BURST)

This test couples BURSTs composed of a number of fast transient to the equipment power ports. The significant elements of this test are the high amplitude, the short rise time, the repetition frequency and the low transient energy.

The waveform used in this test standard is representative of disturbances that may be caused by switching transients (inductive load interruption, rebound of relay contacts, computer circuits, spark in air produced by unplugging, etc.). The characteristics of a BURST are:

- Rise time: (5 ± 1.5) ns,
- Pulse width: (50 ± 15) ns,
- Burst duration: (15 ± 3) ms at 5 kHz,
- Burst period: (300 ± 60) ms,

- Peak voltage: 0.5 to 4 kV (according to the level of severity).

Fig. 3 displays the train of pulses BURSTs and shows details of a BURST wave.

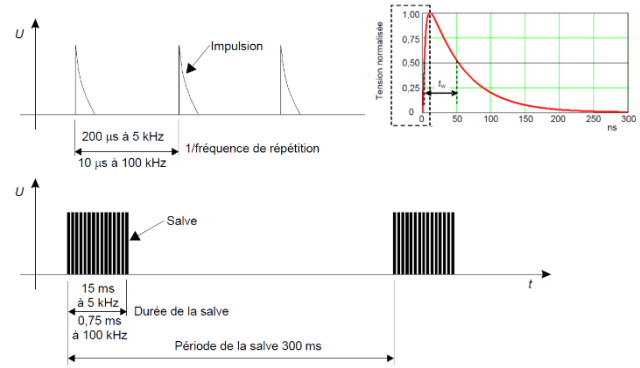


Fig. 3. BURSTs signal.

B. EN 61000-4-5 standard-Surge immunity

This test evaluates the effects of the transients associated with power system switching (such as capacitor bank switching), switching devices (e.g. transistors, thyristors, etc.), various system faults (short circuits...) as well as surge voltages produced by lightning stroke (direct or indirect stroke).

In TABLE III, parameters for open-circuit voltage and short-circuit current are specified.

TABLE III.
SURGE PARAMETERS.

	Front time (T1)	Duration (T2)
Open-circuit voltage	1.2 μ s	50 μ s
Short-circuit current	8 μ s	20 μ s

The surge is applied directly from the generator output terminals according the specifications in Table III. Fig 4 shows the voltage waveform of a surge at 1kV.

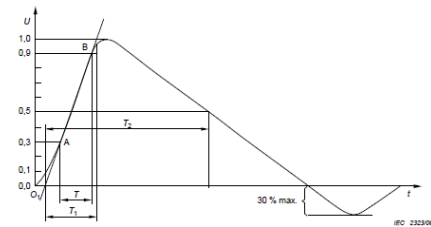


Fig. 4. Open circuit voltage representation.

C. EN 61000-4-11 standard-voltage dips and voltage variations immunity

This test evaluates the effects of short dips and breaks of equipment power supply caused by faults in the network, primarily short circuits or sudden large changes of load. These phenomena are characterized in term of the deviation from the rated voltage and duration. Voltage dips are simulated over a period of 500 ms for a voltage level of 70% of the rated voltage.

For voltage variations, the voltage decreases linearly to the reduced voltage and then goes up linearly to the nominal

value. This is the typical power supply profile when a motor starts. The rise and fall times are in the order of 2 s and the reduced voltage is 70% of the rated voltage.

In Fig. 5 is illustrated a typical theoretical voltage dip.

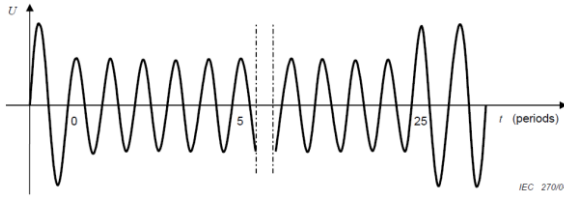


Fig. 5. Voltage dip.

IV. INFLUENCE OF EMI PERTURBATIONS

The influence of EMI perturbations are presented in this section. In the experimental test bench, different household appliances are connected in simple and masking configurations according to TABLE IV. Waveforms in the time domain and spectral densities of recorded currents are obtained. The scope of our study is limited to a frequency band up to 100kHz as is typical of AFCI current sensors.

TABLE IV.
LOAD USED IN THE EXPERIMENTAL TEST BENCH.

Configuration	Appliance	Power [W]
Simple	Resistor = 100 Ω	1500
	Vacuum cleaner	1600
	1 PC	600
	Drill	400
	Halogen lamp	500
Masking configuration	Vacuum cleaner // Resistor Drill // Resistor	

A. Temporal analysis

The surge emulation (EN 61000-4-5 standard) is produced in the circuit by the EMI generator supplying a resistive load. A surge event is generally considered as a non-repetitive phenomenon in a short time interval. The surge voltage inserted in the experimental power line produces variations in the line current (Fig. 6).

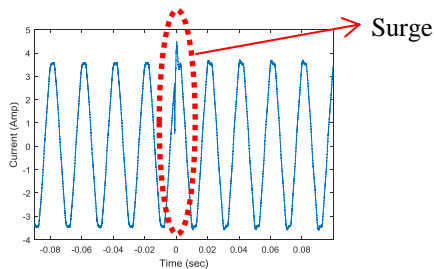


Fig. 6. Resistor current.

The disturbance causes a current variation (visible at $t = 0$ s) of rather short duration (a half cycle).

The tripping of an arc fault circuit breaker can only be done in presence of a fault maintained over several periods of the signal. Surge perturbation cannot be interpreted as an arc fault.

On the other side the BURST, voltage dip and voltage variations generated according to EN 61000-4-4 and EN 61000-4-11 standards are inserted in our experimental power line

using a vacuum cleaner, 1 PC, a drill and a halogen lamp as loads.

Fig. 7a shows the current line of a halogen lamp in stationary operation mode in simple load configuration. A BURSTs sequence with duration of 100ms is capable to disturb the proper functioning of the appliance. In Fig. 7b, BURSTs are inserted periodically in the transient operation mode of a vacuum cleaner. A BURSTs sequence with a time duration fixed to 200ms is firstly injected in section A (transient part), then in section B (transition between the transient and stationary part) and finally in section C (steady state). BURSTs produce significant signal distortion.

In Fig. 7c is illustrated the current line of a vacuum cleaner in transient operation in masking load configuration. The temporal evolution of the current is constituted by a transient part, a transition state and a steady state part. A BURSTs sequence of 200ms is injected in this last part. The masking effect reduces the signal distortion.

Fig. 7d displays the current and voltage in stationary operation for a PC. A voltage dip generation of 500ms produces current with slight incremental amplitude variations and transient behavior. A current spike is observed at 0.58s. On the other side, in Fig. 7e the current in stationary operation for a vacuum cleaner is shown. In this case, the current amplitudes drop abruptly by the injection of a voltage dip. In the graphic, amplitudes in sections A and B have average values of 10 A and 12 A respectively. The transient effect in the current induced by a voltage dip can significantly affect the AFCI performance.

In Figs. 7f and 7g are displayed the transient current for a PC (simple load configuration) and a vacuum cleaner (masking load configuration). The 2s voltage variation inserted in the circuit produces current amplitude variations. In Fig. 7f the current of the PC has incremental amplitudes (above 5A) and an opposite trend with respect to the voltage variation. However, in Fig. 7g the current variations have the same trend as the voltage variation. Unlike voltage dip, the voltage variations are inserted smoothly; however, they can also generate important disturbances that are able to trigger false trips.

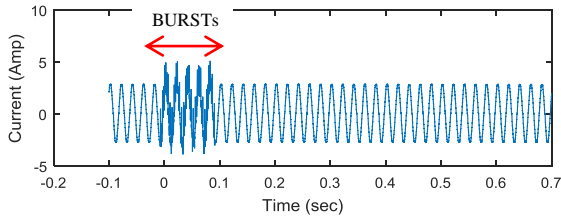
Fig. 8 shows a comparison between the BURST and a series arc fault inserted in the current line (for a PC). The distortions obtained in the time domain are comparable. In this context, EMI perturbations can really affect the good AFCI performance.

B. Spectral analysis

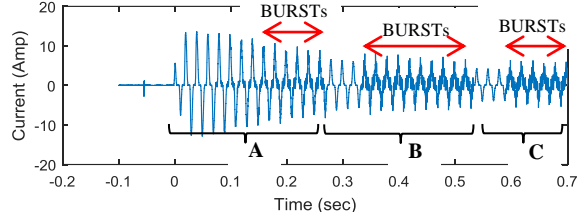
Spectral analysis is generally used in the literature to identify series arc faults by comparing the spectral density of measured current in normal and in fault operations. Fault detection methods based on the energy variation resulting from the spectral coefficients is performed in a variety of bands ranging from low frequencies up to 20kHz [15]-[19]. However, EMI perturbations can also produce spectral densities comparable to arcing faults in this frequency band and can lead to false detections of AFCI.

In Fig. 9 are displayed different spectral densities for currents obtained from tests using appliances presented in TABLE IV.

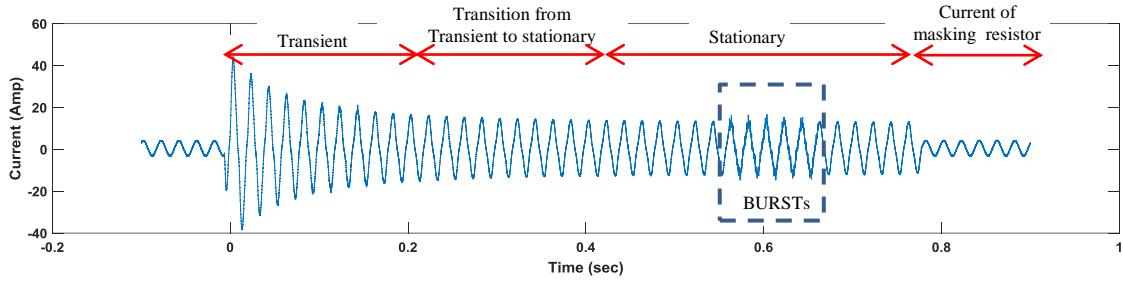
BURST



a) Halogen lamp.

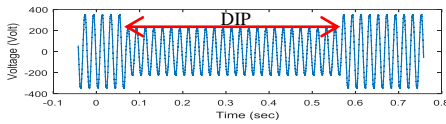
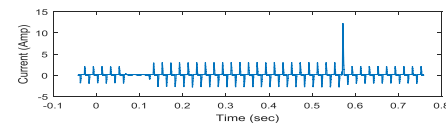


b) Drill.

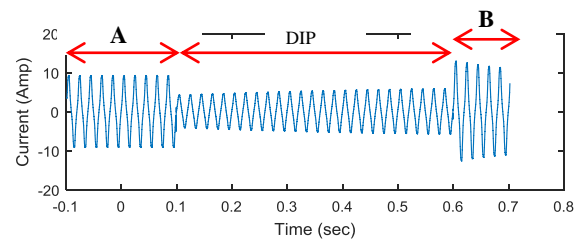


c) Vacuum cleaner – masking configuration.

VOLTAGE DIP

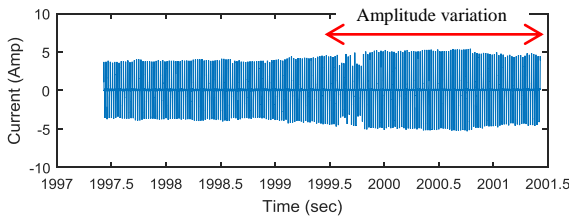


d) IPC.

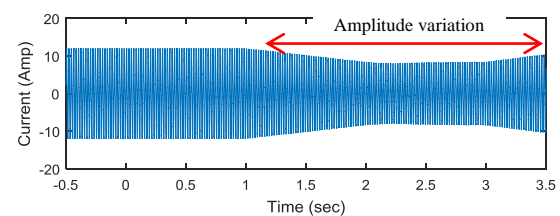


e) Vacuum cleaner.

VOLTAGE VARIATION



f) Current variation (IPC).



g) Current variation-masking configuration (Vacuum cleaner).

Figure 7. Current of the line considering different EMI perturbations.

The spectral density for a PC in simple configuration shows an important influence of the BURSTS in comparison to voltage dip and voltage variations (Figs. 9a, 9d, 9g). In this regard, series arc faults can only be distinguished from BURST signal in a frequency band around 10kHz.

The spectral density for a vacuum cleaner (Figs. 9b and 9h) presents significant EMI perturbations which are difficult to identify from series arc faults. The BURSTS and voltage variations generated taking into account simple circuit

configuration make difficult the series arc fault identification. The frequency band of 10kHz – 100kHz is not representative to confirm the arc fault presence. In the case of voltage dip (Fig 9b), an arc fault can be identified using a frequency band of 20kHz – 100kHz. In the case of masking load configuration (Fig. 9i) tested under voltage variations, the masking effect produced by the 100Ω resistor, reduces the influence of EMI perturbations. In this case the arc fault identification is possible in a frequency band of 50kHz – 100kHz.

The spectral density for a drill (Fig. 9f) shows EMI perturbations originated by voltage dip in simple circuit configuration. In this case a series arc fault is identified in the frequency band of 10kHz – 100kHz.

Finally the most difficult case is presented in Fig. 9c (simple configuration) for a halogen lamp in which is not possible to identify a series arc fault from EMI perturbations produced by the BURSTS.

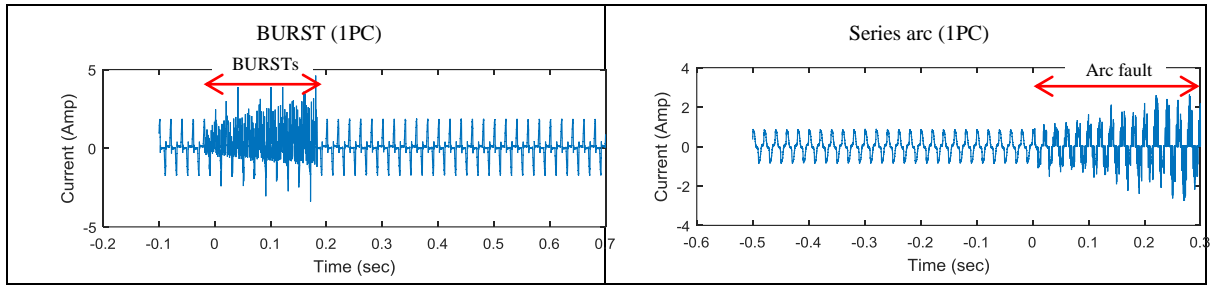


Figure 8. Currents comparison (BURSTS / series arc).

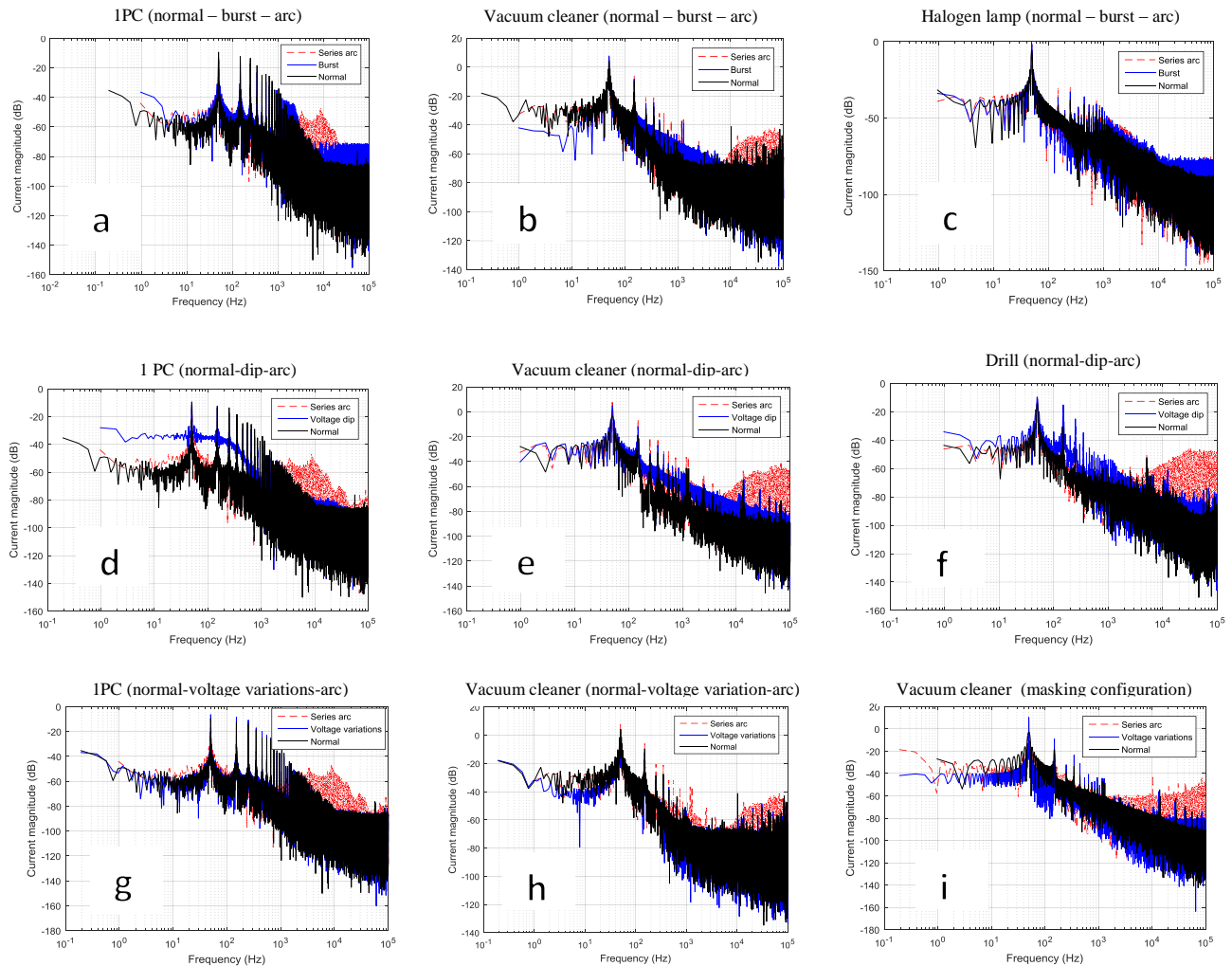


Figure 9. Spectral density for different appliances.

VI. CONCLUSION

More and more domestic electronic household appliances produce EMI interferences in electrical networks (switch devices, load variations, motor starting, etc.). These perturbations can be in some cases interpreted as arc faults and causes the tripping of an arc fault circuit breaker (false detections). In this paper experiments have been carried out to generate perturbations according to the UL 1699 and IEC 62606 standards using the EMTEST UCS500 M4 generator. The perturbations generated in this work according to EN 61000-4-4, EN 61000-4-5 and EN 61000-4-11 standards are fast transient perturbations (BURT), surge, voltage dip and voltage variations. The current sensor in a circuit breaker has a limited frequency band. Thus, we limited our analysis to the 0-100kHz frequency band.

The EMI perturbations have characteristics similar to series arc faults. Frequency analysis shows that the arc fault detection in the presence of EMI perturbations is difficult to achieve if we use a single frequency band for analysis. Thus, the frequency band has to change as a function of different kinds of EMI perturbations and loads.

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