THE CONCEPT OF SHORT-CIRCUIT POWER AND THE ASSESSMENT OF THE FLICKER EMISSION LEVEL

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Summary

The paper starts with an overview of different concepts of short-circuit power: the IEC standard, the effective and the apparent short-circuit power. The short-circuit power is a key concept in characterising the ability of a power system to feed fluctuating loads without excessive flicker levels. Its apparent value (from measurements) is generally higher than its standard value (from calculations in standard conditions).

The contractual reference short-circuit power is the value which will be used as contractual reference in the flicker emission assessment and can be based on one of the three above concepts. Important is to make a clear choice for the contractual reference short-circuit power.

Field experiences have demonstrated that the existing flicker emission assessment approaches (“the simplified approach” and the “voltage drop approach”) do not always lead to good results. The existing approaches suppose that the active power variations and the resistive component of the power system impedance can be neglected.

The present paper demonstrates that neglecting the network resistance can lead to an important underestimation or overestimation of the voltage drop (or flicker emission) when the active power variations are important and when the network impedance angle is small (say smaller than 85°).

A new assessment technique “the load current approach”, is proposed to overcome this problem.
The three approaches have been applied on two DC electrical arc furnaces of different technologies, see Table 1.

Table 1 : Flicker emission (Pst,99%) of the EAF’s using the three different approaches

		EAF 1	*EAF 2*
(1)	*Simplified approach*	0.89	1.41
(2)	*Voltage Drop approach*	0.86	1.53
(3)	*Load Current approach*	1.16	1.24

It appears that the Load Current approach yields less favourable results for EAF1 but more favourable results for EAF2.

Conclusions

The short-circuit power is a key concept in characterising the ability of a power system to feed fluctuating loads without excessive flicker levels. Its apparent value (from measurements) is generally higher than its standard value (from calculations in standard conditions). Important is to make a clear choice for the contractual reference short-circuit power.

For assessing a flicker emission level, the “simplified approach” (flicker measurements at the load side of the step-down transformer) can be easily implemented with a standard flickermeter and leads to a good estimation when:

1. the background flicker at the secondary side of the transformer is negligible
2. the power variations are mainly reactive
3. the network resistance is negligible

The “voltage drop approach” (voltage waveform measurements at both sides of the step-down transformer) can be used in the same conditions (reactive power variations in purely inductive network), especially when the background flicker at the secondary side of the transformer is too important. A further advantage with respect to the "simplified approach is that it is based on a well-known impedance".

The “load current approach” (current and voltage waveform measurements at the connection point) yields the best results because it takes the network resistance into account. When the active power variations are important (as compared to the reactive power variations) and/or the network impedance angle is small (for instance < 85°) it is recommended to use this method.

The influence of the network resistance on the flicker emission level can be negative or positive, depending on the angle of the power variations. This should be taken into account when choosing the technology – and the control strategy - for an arc furnace or a fluctuating load in general.

LE CONCEPT DE PUISSANCE DE COURT-CIRCUIT ET L’EVALUATION DU NIVEAU D’EMISSION DE FLICKER

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Résumé

Le rapport débute en donnant un aperçu des différents concepts de puissance de court-circuit : la valeur normalisée CEI, la valeur effective et la valeur apparente. La puissance de court-circuit permet de caractériser l’aptitude d’un réseau d’alimenter des charges fluctuantes sans produire des niveaux de flicker excessifs. La valeur apparente (mesurée) est généralement plus élevée que la valeur normalisée.

La puissance de court-circuit contractuelle de référence est la valeur qui sera utilisée lors de l’évaluation du niveau d’émission. Elle peut être basée sur un des trois concepts mentionnés ci-dessus. Il est important de faire un choix univoque de la puissance de court-circuit contractuelle.

Des expériences de terrain ont démontré que les méthodes d’évaluation existantes (« l’approche simplifiée » et « l’approche chute de tension ») ne mènent pas toujours à des résultats satisfaisants. Les approches existantes supposent que les variations de puissance active et la composante résistive du réseau sont négligeables.

Le rapport démontre que le fait de négliger la résistance du réseau peut induire une sous- ou surestimation de la chute de tension (ou de l’émission flicker) quand les variations de puissance active sont importantes et quand la phase de l’impédance du réseau est faible (e.g. plus petite que 85°).

Une nouvelle technique d’évaluation, « l’approche courant de charge », est proposée afin de surmonter ce problème.

Les trois approches ont été appliquées sur deux fours à arcs DC de technologie différentes, elles mènent au résultats du tableau 1.

Tableau 1 : Emission Flicker (Pst,99%) des fours à arcs, utilisant les trois approches différentes.

		EAF 1	*EAF 2*
(1)	*Approche simplifiée*	0.89	1.41
(2)	*Approche chute de tension*	0.86	1.53
(3)	*Approche courant de charge*	1.16	1.24

Ceci démontre que l’approche « courant de charge » donne des résultats moins favorables pour le four 1, mais plus favorable pour le four 2.

Conclusions

La puissance de court-circuit permet de caractériser l’aptitude d’un réseau à alimenter des charges fluctuantes sans produire des niveaux de flicker excessifs. La valeur apparente (mesurée) est généralement plus élevée que la valeur normalisée (calcul en condition normalisée). Il est important de faire un choix univoque de la puissance de court-circuit contractuelle.

Pour l’évaluation des niveaux d’émission de flicker, l’approche simplifiée (mesures flicker a coté charge du transformateur) peut être appliquée avec un flickermètre standard et peut mener à une bonne estimation quand :

1. le flicker de fond au secondaire du transformateur est négligeable
2. les variations de puissance sont essentiellement réactives
3. la résistance du réseau est négligeable

L’approche « chute de tension » (mesure de formes d’ondes de chaque côté du transformateur) peut être utilisée dans les mêmes conditions (variations de puissance réactives dans un réseau purement inductif), en particulier quand le flicker de fond est trop important. Le fait que cette méthode est basée sur une impédance connue, est un avantage supplémentaire.

L’approche « courant de charge » (mesure de formes d’ondes de courant et de tension au point de couplage commun) donne les meilleures résultats car elle tient compte de la résistance du réseau. Quand les variations de puissance sont importantes (par comparaison avec les variations de puissance réactive) et/ou quand l’angle de l’impédance du réseau est faible (e.g. plus petite que 85°) il est recommandé d’utiliser cette méthode.

L’influence de la résistance du réseau sur le niveau d’émission flicker peut être négative ou positive, selon l’angle des variations de puissance. Ceci devrait être pris en considération lors du choix de la technologie et de la stratégie de commande d’un four à arc ou d’une charge fluctuante en général.

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1 Introduction

Field experiences have demonstrated that the existing flicker emission assessment approaches do not always lead to good results. The existing approaches ("the simplified approach" and the "voltage drop approach") suppose that the active power variations and the resistive component of the power system impedance can be neglected. The present paper demonstrates that this hypothesis may lead in some cases to important errors and proposes a new assessment method "the load current approach", which takes the network resistance and the active power fluctuations into account, to overcome this problem.

2 Standard, effective, apparent and contractual short-circuit power

The concept of short-circuit power has been extensively discussed in [1]. We only reproduce here a brief summary of this analysis.

2.1 IEC standard short-circuit power

The basic definitions of short-circuit conditions are given in the IEC Standard 909 [2]. This standard is based on the calculation of symmetrical initial short-circuit current (I''_{sc}), for *unloaded networks*, i.e., in the absence of passive loads and any shunt capacitance. In order to calculate I''_{sc}, the Thévenin's Theorem is applied to the unloaded network with a source voltage equal to cU_n (U_n being the nominal voltage).

IEC specifies two standard values for the factor c. The *« maximum value »* is to be used for apparatus rating purposes and it is fixed at 1.1 for HV systems. The *« minimum value »* is to be used for other purposes such as the control of motor starting conditions [2], which is typical of fast voltage fluctuations problems such as flicker, and it is fixed at 1.0 for HV systems. The (IEC standard) short-circuit power is then defined as:

$$S''_{sc} = \sqrt{3}\ U_n\ I''_{sc}$$

The IEC approach perfectly suits, either for equipment rating purposes (I''_{sc} alone is derived from the above Standard, because it is used in conjunction with the "highest voltage for equipment" as defined in other IEC Standards), or for non-critical voltage fluctuations problems.

2.2 Effective short-circuit power in operating conditions

For voltage fluctuations problems that are critical in terms of acceptability, there is room for a second approximation of short-circuit power, either aiming at a reliable assessment of power system ability to supply a big industrial plant at the stage of design or site selection, or in order to check field measurements against pre-assessed calculations.

This second approximation enables to make further calculations following the theoretical definition of physical short-circuit power, *based on the actual voltage* and taking the shunt elements into account.

In normal operating conditions (see Figure 1), the network is loaded. We consider a supply substation to a major industrial site (STo), the substation voltage is at least equal to the nominal value. To get U_n at the substation, the setting of the source emf needs to be put at U_n/μ ($\mu < 1$[1]). Because of the increase in voltage, the physical short-circuit current also increases by the same factor. Then, the physical short-circuit power increases pro-rata to $1/\mu^2$, in compliance with theory. Moreover, if the voltage at the industrial substation is higher than U_n, which is common practice in operating conditions, the increase is still more important.

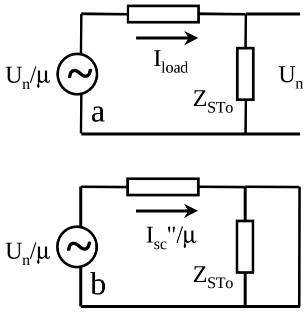

Figure 1 : Increase in short-circuit current in a loaded network operated at U_n at the load side ($\mu < 1$)
a: initial situation with loaded network
b: short-circuit situation

These considerations lead to propose the concept of *effective short-circuit power* in operating conditions, defi-

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[1] The load is usually mainly inductive

ning it as the physical short-circuit power on the *loaded network* and at the actual voltage at the substation.

2.3 Apparent short-circuit power

In the preceding analysis, the loads are taken into account as linear elements, i.e. assumed to be represented by constant impedances. However, it has been established in the past that the loads do usually not behave as constant impedances. They may exhibit voltage dependent characteristics, leading for instance to reactive power-voltage functions very different from the classical second degree relationship. The general form is as follows:

$$\frac{Q}{Q_o} = \left(\frac{U}{U_o}\right)^{\alpha}$$

Exponents α between 0,5 and 18 are found in the literature, depending on the type of loads.

In the presence of reactive power fluctuations, this non-linear behaviour may influence significantly the voltage fluctuations. The usually measured effect is a supplementary decrease of the variations, which can be interpreted as the consequence of an “apparent” short-circuit power, being increased with respect to the standard or even the effective short-circuit power.

This approach yields information to be used complementarily to the IEC Standard in special discussions and measurements, e.g. as in the context of flicker emission level assessment.

2.4 Contractual reference short-circuit power

The *contractual reference short-circuit power* is the value which will be used as contractual reference in the flicker emission assessment. It can be one of the three above mentioned short-circuit powers.

Whatever the choice, it is a fact that the actual value will vary with the time. Even at the commissioning time, it is generally different from the contractual value.

3 Approaches for the assessment of the flicker emission level [3]

3.1 Introduction

The technical report IEC 61000-3-7 [4] outlines the principles to assess emission limits for the connection of fluctuating loads to the public network power system and gives the definition of the flicker emission level:

“*The flicker emission level from a fluctuating load is the flicker level which would be produced in the network if no other fluctuating load was present.*”

The above mentioned report does however not explain how to measure and assess the flicker emission level. Because of the background flicker, the flicker emission level cannot be determined from a simple voltage measurement at the PCC (point of common coupling). In this chapter three different assessment techniques are described to overcome this problem.

3.2 The effect of the commonly neglected network resistance on the flicker emission level

The network resistance is often neglected in flicker emission assessments.

The voltage drop provoked by a load switching can be described by the equation:

$$\Delta U \cong R \cdot I \cdot \cos\varphi + X \cdot I \cdot \sin\varphi$$

When the resistive component is neglected, the voltage drop becomes:

$$\Delta U = X \cdot I \cdot \sin\varphi$$

Leading to the underneath relative error:

$$\varepsilon = \frac{-\cos\varphi}{\cos\varphi + \sin\varphi \cdot tg\theta}$$

– θ : network impedance angle
– φ : load current angle

which is represented in
Figure **2**.

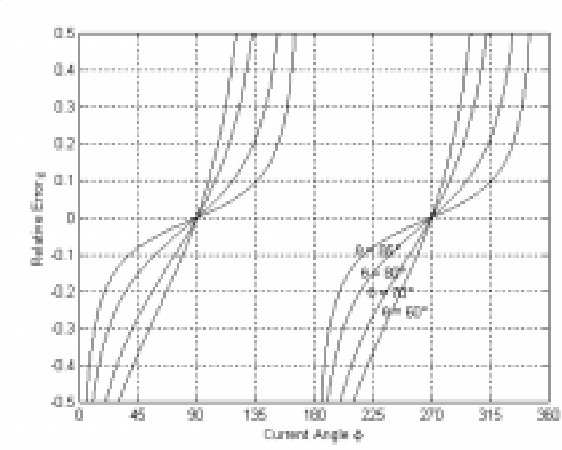

Figure 2 : Relative error when neglecting the network resistance ($\overline{Z}' = j \cdot X$)

It is shown that neglecting the network resistance can lead to an important underestimation or overestimation of the voltage drop (or flicker emission) when the active power variations are important and when the network impedance angle is for instance smaller than 85°.

3.3 Method 1 : simplified approach

When other fluctuating loads are operating in the electrical vicinity, the background flicker on the PCC (B) cannot be neglected (**Figure 3**). At the secondary side of the transformer (A) however, the dominance of the investigated installation in the global flicker level increases and the influence of other sources can often be neglected, especially when the 99th percentile of Pst is considered (IEC 61000-3-7).

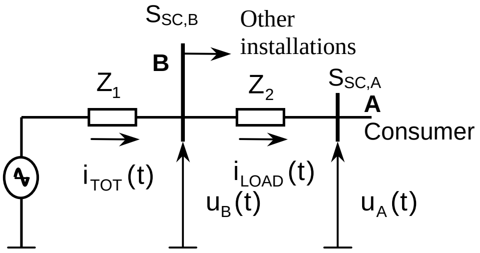

Figure 3 :
Network configuration for the "simplified approach"

The method consists in measuring the flicker level at the secondary side of the transformer and to transpose it to the primary side :

$$P_{ste}(B) \approx \frac{X_1}{X_1 + X_2} P_{ste}(A)$$

$$P_{ste}(B) \approx \left| \frac{Z_1}{Z_1 + Z_2} \right| \cdot P_{ste}(A) = \frac{S_{SC,A}}{S_{SC,B}} P_{ste}(A)$$

with :

- X_1 = network reactance
- X_2 = transformer reactance
- Z_1 = network impedance
- Z_2 = transformer impedance
- $S_{sc,A}$ = short-circuit power in point A
- $S_{sc,B}$ = short-circuit power in point B (PCC)

The transposition is, strictly speaking, only valid in the case of reactive power fluctuations in a purely inductive network.

3.4 Method 2 : voltage drop approach[2]

3.4.1 Description

A *known impedance*, in most cases the *transformer impedance* feeding the particular load, between points A (=consumer) and B (=point of common coupling) is used to assess the emission of the fluctuating load. Simultaneous voltage waveform measurements in points A and B have to be made to calculate the emission level (**Figure 4**).

All quantities are first expressed in p.u. (**Figure 4**). To obtain the voltage waveforms in p.u., the measured waveform signals $(u_{A,m}(t) \text{ and } u_{B,m}(t))$ have to be divided by the RMS voltage over a 10 min interval (= reference period for calculating the Pst value):

$$u_A(t) = \frac{u_{A,m}(t)}{U_{ARMSSH}} \qquad u_B(t) = \frac{u_{B,m}(t)}{U_{BRMSSH}}$$

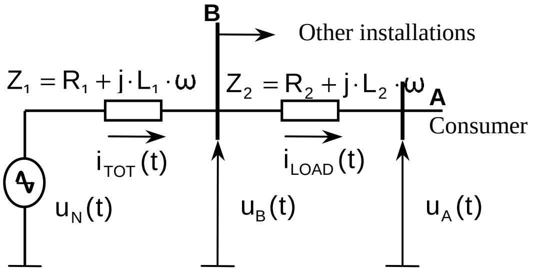

Figure 4 : configuration for assessment of the emission with the “voltage drop approach”

The voltage fluctuations over the impedance Z_2, caused by the load current $i_{LOAD}(t)$, are described by the underneath equation:

$$\Delta u_{AB}(t) = u_A(t) - u_B(t)$$
$$= R_2 \cdot i_{LOAD}(t) + L_2 \cdot \frac{di_{LOAD}(t)}{dt} \approx L_2 \cdot \frac{di_{LOAD}(t)}{dt}$$

The voltage fluctuations $\Delta u_{AB}(t)$ are subtracted from a sinusoidal voltage source of 1 p.u., with the same electrical angle as the measured voltage $u_B(t)$, to obtain the input signal for the digital flickermeter:

$$\sqrt{2} \cdot \sin(\omega t + \alpha) - \Delta u_{AB}(t)$$

The accordingly calculated Pst value is the *emission level* of the installation *related to the chosen reference impedance Z_2.*

To determine the emission level at the PCC, the obtained emission level has to be transposed to the contractual short-circuit level at the PCC.

$$P_{ste}(PCC) = \frac{Z_1}{Z_2} \cdot P_{ste}(Z_2)$$

with:

- Z_1 = network impedance
- Z_2 = known impedance (≈ transformer reactance)

This equation is, strictly speaking only valid when the impedances Z_1 and Z_2 are purely reactive. Approximations are done when applying this method, the two most important are mentioned in the paragraphs below.

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[2] The first development to measure the flicker emission level of a fluctuating load, related to the transformer impedance was made by M. Sakulin [5],[6]

3.4.2 *First Approximation : the impedance angle of the transformer is supposed to be the same as the impedance angle of the network*

The flicker emission obtained with the 'voltage drop approach' is related to the chosen reference impedance. In most cases the reference impedance is a transformer, thus almost purely inductive. The consequence is that only the reactive power variations are visible. The active power variations remain invisible, although they will cause a voltage drop over the network resistance and influence the emission level at the PCC.

When relating the emission level to the network impedance at the PCC, the assumption has to be made that the resistance of the network can be neglected. Depending on the phase angle of the current variations and the network impedance angle this will result in an error, as illustrated in

Figure 2.

3.4.3 *Second Approximation : the phase shift over the network is considered to be negligible*

In the network of **Figure 5** (the resistances are neglected), the voltage drop can be calculated with the underneath equation:

$$\Delta U_{NB} \cong X_1 \cdot I \cdot \sin\varphi$$

This formula shows that the angle α between the load current and the voltage source U_N is very critical in the determination of the voltage drop and the flicker emission.

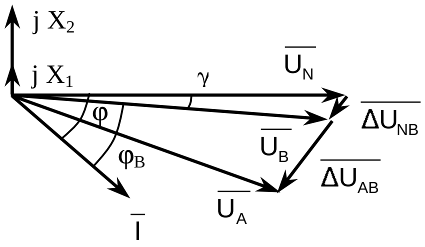

Figure 5 : phase shift over network and transformer impedance

In the voltage drop approach the sinusoidal voltage source has the same angle as the primary voltage of the transformer (U_B), the voltage drop over the transformer is in this case:

$$\Delta U_{AB} \cong X_2 \cdot I \cdot \sin\varphi_B \rightarrow$$

$$\Delta U_{NB} = \frac{X_1}{X_2} \cdot \Delta U_{AB} \cong X_1 \cdot I \cdot \sin\varphi_B$$

The voltage drop (or the current) exhibits thus no longer the correct phase shift, due to the phase shift γ over the network impedance. A relative error $\varepsilon = \frac{\sin(\varphi - \gamma)}{\sin\alpha} - 1$ is made.

When the current variations are purely reactive, no error will occur, because the voltage U_N and U_A will be in phase.

3.5 Method 3 : load current approach

This approach requires *waveform* measurements of the *load current* [$i_{LOAD}(t)$] and the voltage [$u_m(t)$] at the PCC. The calculation of the emission level of the fluctuating load is done in two steps

3.5.1 *Step 1:simulation of voltage $u_e(t)$ (elimination of background fluctuations)*

The measured load current $i_{LOAD}(t)$ is injected in the ideal grid model of figure 6 b, to determine the emission voltage $u_e(t)$, the voltage which would be obtained at the PCC, if the load was the only fluctuating load in the grid.

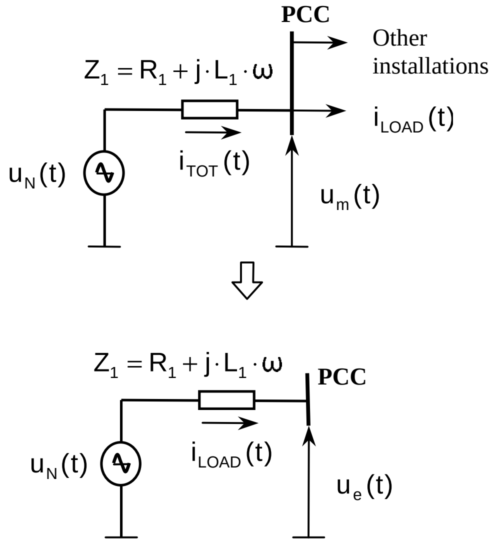

Figure 6: configuration for assessing the emission level with the 'load current approach'
measurement configuration - simulation configuration

The phase angle of the simulated voltage $u_e(t)$ has, at every moment, to be the same as for the measured voltage $u_m(t)$, to preserve the correct phase angle with the load current $i_{LOAD}(t)$, i.e. to respect the reactive and active power demand of the load at the PCC.

The voltage source should as a result have:

– the same electrical angle as the fundamental of the voltage[3]: $u(t) = u_m(t) + R_1 \cdot i_m(t) + L_1 \frac{di_m(t)}{dt}$

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[3] In contrast to the voltage drop approach, the phase shift γ over the network impedance is taken into account. In this way the correct phase angle is preserved between the calculated voltage (emission voltage $\underline{U}_E$) and the measured load current at the PCC.

- the amplitude of the voltage source should be constant and equal to $\frac{\sqrt{2}}{\sqrt{3}} \cdot U_n$, U_n being the nominal or reference voltage of the grid.

The voltage source should be an ideal source without any disturbance and fluctuation, the flicker and disturbances on the voltage source should be completely eliminated to obtain a perfect sinusoidal source:

$$u_n(t) = \frac{\sqrt{2}}{\sqrt{3}} \cdot U_n \cdot \sin(\omega t + \alpha)$$

Knowing the instantaneous voltage of the voltage source $u_n(t)$ and the instantaneous current $i_m(t)$, the emission voltage $u_e(t)$ can be calculated using the underneath equation.

$$u_e(t) = u_n(t) - R_1 \cdot i_m(t) - L_1 \frac{di_m(t)}{dt}$$

3.5.2 Step 2 : digital flicker meter

A digital flicker algorithm [7] is used to deduce the instantaneous flicker Pf and the statistical values Pst and Plt out of the voltage waveform $u_e(t)$.

4 Assessment of the flicker emission level of two DC EAF

4.1 Introduction

The flicker emission of two Direct Current Electrical Arc Furnaces (DC EAF) have been assessed using the three described assessment techniques. Both arc furnaces have a nominal power of 140 MVA.

EAF 1 is a DC EAF with free-wheeling diodes plus shifting control [8]. The particular technology of this arc furnace enables to smooth the inductive current fluctuations and to reduce the flicker emission in a *purely inductive* network, thus allowing a smaller SVC (60 MVAr).

Table 1 :

- IEC 909 standard short-circuit powers (c = 1,0) = contractual reference short-circuit powers
- Transformer short-circuit powers
- corresponding impedances (base 220 kV)

	S_{sc} *(GVA)*	*Z (Ω)*
EAF 1		
PCC	5.00 ∠ 279°	1.51 + j 9.56
HV-MV transfo	1.00 ∠ 272°	1.29 + j 48.4
MV-busbar	0.753 ∠ 273°	3.70 + j 64.2
EAF 2		
PCC	5.00 ∠ 279°	1.51 + j 9.56
HV-MV transfo	1.00 ∠ 271°	0.97 + j 48.4
MV-busbar	0.761 ∠ 273°	3.28 + j 63.5

EAF 2 is a classical DC EAF with a thyristor Graetz bridge in 12-pulses arrangement, causing a current with an important inductive component and compensated with a big SVC of 110 MVAr.

The contractual reference short-circuit powers for the flicker emission assessments are considered to be the IEC standard short-circuit powers, without considering hereafter the effective and apparent short-circuit powers.

4.2 Power fluctuations

The fundamental power fluctuations on a 20 ms time base are given for a 2 s time interval for EAF 1 & 2, SVC and filter installations included in **Figure 7** and **Figure 8**.

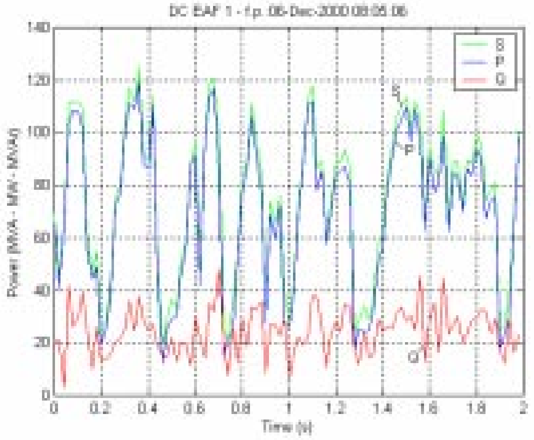

Figure 7 : 20 ms – 50 Hz Power variations over time interval of 2 s – EAF 1

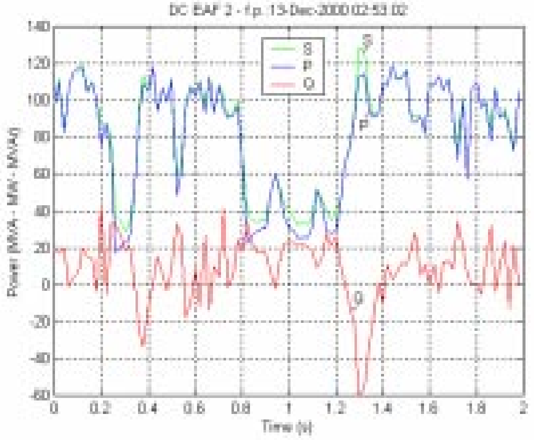

Figure 8 : 20 ms – 50 Hz Power variations over time interval of 5 s – EAF 2

The arc furnaces seems to have a different behaviour.

In the case of EAF 1, the active power variations seems to have the same sign as the reactive power variations. In the case of EAF 2 the active and reactive power variations seems to be opposite. A statistical analysis of the angle of the most important reactive power variations over an observation period of a complete day confirms these impressions : the angle is mainly between 0° and 90° for EAF 1 and between 90° and 180° for EAF 2.

The voltage variations can be calculated with the underneath equation:

$$\frac{\Delta U}{U} \cong \frac{R \cdot \Delta P + X \cdot \Delta Q}{U^2}$$

We see that the voltage variations will increase for EAF 1 (decrease for EAF 2) when taking the active power variations into account. The flicker emission should be influenced in the same way.

Another difference between both furnaces is the amplitude of the power variations. The cumulated probability functions for the active and reactive power variations for both arc furnaces are represented in **Figure 9**.

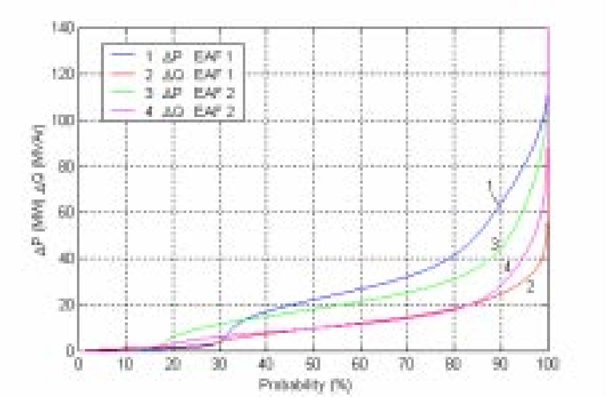

Figure 9 : EAF 1 – EAF 2
CPF most important reactive and active power variations

The 99th percentiles for the power fluctuations are given in table 2.

Table 2 : 99th percentiles power variations

	95^{th} percentile	
	ΔP (MW)	*ΔQ (MVAr)*
EAF 1	81	31
EAF 2	63	42

The reactive power variations are more important for EAF 2 than EAF 1. The opposite is valid for the active power variations.

4.3 Flicker emission assessment

4.3.1 Simplified approach

The flicker level[4] at the MV busbar of both EAF is given in the table 3. The emission of the installation at the PCC can be estimated, using the underneath equation:

$$P_{ste}(PCC) = \frac{X_{HV}}{X_{MV}} P_{st}(MV)$$

Table 3 : Flicker emission (Pst,99%) of the EAF's using the "simplified approach"

		EAF 1	*EAF 2*
(1)	*MV busbar*	6.00	9.39
(2)	*Simplified approach*	0.89	1.41

4.3.2 Voltage drop approach

The 99th percentiles of the emission related to the transformer impedance are calculated. The emission at the PCC can be obtained with:

$$P_{ste}(PCC) = \frac{X_{HV}}{X_{Transfo}} \cdot P_{ste}(transfo)$$

Table 4 : Flicker emission (Pst,99%) of the EAF's using the "voltage drop approach"

		EAF 1	*EAF 2*
(3)	*HV-MV transformer*	4.34	7.75
(4)	*Voltage Drop Approach*	0.86	1.53

4.3.3 Load Current Approach

The flicker emission is assessed with the load current approach. The flicker emission obtained with this method and related to the contractual reference short-circuit power can be found in table 5.

Table 5 : Flicker emission (Pst,99%) of the EAF's using the "load current approach"

		EAF 1	*EAF 2*
(5)	*Load Current Approach*	1.16	1.24

4.3.4 Assessment results

In the case of the arc furnaces, the "simplified approach" and the "voltage drop approach" do not give good results, the main reason is that the angle of the reference impedance is not representative for the impedance angle at the PCC:

- transformer : $\theta \approx 89°$ ↔ HV busbar : $\theta \approx 81°$
- MV busbar : $\theta \approx 87°$↔ HV busbar : $\theta \approx 81°$

In the voltage drop approach the reference impedance is almost purely inductive, the effect of active current fluctuations remain for that reason invisible. When a pure reactance is used in the load current approach

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[4] 99th percentile of Pst

similar results are obtained as with the voltage drop approach.

When taking the network resistance into account the flicker emission (99th percentile) will:

- *increase* with 35 % in the case of EAF 1
- *decrease* with 15 % in the case of EAF 2

The network resistance has an amplifying impact on the emission level for EAF 1 and an attenuating impact on the emission level for EAF 2. This effect can be explained when analysing the angle of the power variations (§ 4.2) and is a result of the difference in technology. It seems that the technology with free-wheeling diodes and shifting control (EAF 1) looses a part of its advantages when taking the effect of the network resistance into account in the case of non-negligible network resistance.

5 Conclusion

The short-circuit power is a key concept in characterising the ability of a power system to feed fluctuating loads without excessive flicker levels. Its apparent value (from measurements) is generally higher than its standard value (from calculations in standard conditions). Important is to make a clear choice for the contractual reference short-circuit power.

For assessing a flicker emission level, the “simplified approach” (flicker measurements at the load side of the step-down transformer) can be easily implemented with a standard flickermeter and leads to a good estimation when:

1. the background flicker at the secondary side of the transformer is negligible
2. the power variations are mainly reactive
3. the network resistance is negligible

The “voltage drop approach” (voltage waveform measurements at both sides of the step-down transformer) can be used in the same conditions (reactive power variations in purely inductive network), especially when the background flicker at the secondary side of the transformer is too important. A further advantage with respect to the "simplified approach is that it is based on a well-known impedance".

The “load current approach” (current and voltage waveform measurements at the connection point) yields the best results because it takes the network resistance into account. When the active power variations are important (as compared to the reactive power variations) and/or the network impedance angle is small (for instance < 85°) it is recommended to use this method.

The influence of the network resistance on the flicker emission level can be negative or positive, depending on the angle of the power variations. This should be taken into account when choosing the technology – and the control strategy - for an arc furnace or a fluctuating load in general.

References

[1] M. Couvreur, E. De Jaeger, A. Robert, 2000, “Voltage Fluctuations and the Concept of Short-Circuit Power”, CIGRE 2000, report 13/14/36-08

[2] International Electrotechnical Commission, 1988, “Short-circuit current calculation in three-phase a.c. systems”, IEC Standard 909, 1st edition

[3] P. Goossens, A. Robert, E. De Jaeger, “Assessment of the flicker emission of fluctuating loads”, ERA Conference, Quality and security of electric supply – 2001

[4] Technical Report IEC 61000-3-7, Electromagnetic Compatibility (EMC), Part 3 :Limits, Section 7: Assessment of emission limits for fluctuating loads in MV and HV power systems – Basic EMC publication

[5] M. Sakulin, T. Key, “UIE/IEC Flicker Standard for Use in North America, Measuring Techniques and Practical Applications” (Proceedings of the PQA ’97 North America Conference, Columbus OH, USA, March 1997)

[6] M. Sakulin, H. Renner, “Field Experience with the Austrian UIE / IEC Flicker Analysis System” (Proceedings of the XIIth UIE Congress, Electrotech 92, Montréal Canada, 1992, pp. 842 – 85)

[7] W. Mombauer, “Flicker Simulation and Minimisation”, CIRED 1989

[8] J. Du Parc, M. Wursteisen, C. Glinski, “Harmonics and Flicker from DC EAF”, PQA’94, Amsterdam, October 24-27, 1994