# Advanced technology to ensure EAF grid flicker compliance

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*Abstract*— **Electrical Arc Furnace, as one of the most severe loads to be connected to electrical system, is contributing significantly to voltage flicker phenomena on distribution and transmission system level. Despite many known technologies to mitigate EAF induced voltage flicker, in many cases there are still discrepancies between planned and measured voltage flicker level after implementation, which is creating problems with grid code compliance. This paper is showing a novel approach to successfully overcome this problem in any grid. This approach is taking into account all components contributing to voltage flicker. The case is supported by practical measurement results on a high power 30 MVA, 33 kV EAF.**

***Keywords—EAF; SVC; Statcom; harmonics power; voltage flicker***

## I. INTRODUCTION

AC electrical arc furnace is one of the most severe load to be connected in the electrical system. Not only due to the high power demand of EAF compared to the short circuit capacity at PCC, but also due to the fact EAF has unpredictable fluctuating, unbalanced and distorted power demand as its natural characteristic. The EAF power demand is highly inductive since arc voltage and current have to be in phase shift in order to avoid arc extinguishing which makes process even more severe. Therefore it is clear that EAF technology has the most contribution to voltage flickering on distribution and transmission system level.

Traditionally Static VAR Compensator systems are used to mitigate flicker caused by large EAF. The SVC technology has it's own limitations in response time and harmonic mitigation capabilities, which could lead to insufficient flicker suppression if overlooked. In preparation to EAF delivery, careful studies and analysis of system parameters at PCC are taken, in order to plan measures to limit disturbance injection by EAF operation. However in most of the cases this is not an easy task, due to the fact that some of the grid parameters, as well as EAF load parameters, are actually estimates. Additionally, it is usual to take into consideration only active and fundamental frequency reactive power variations, when planning flicker mitigation. This is natural approach since traditionally available technology has not been able to mitigate dynamically fluctuating reactive power due harmonics.

It was seen in practice that, after commissioning of EAF with disturbance mitigation equipment in operation, an actual flicker level is significantly above estimated value.

This is becoming an issue when upon EAF commissioning, both power utility and furnace operator have to prove that the influence of EAF to power quality at PCC is within requirements of the grid code, including flicker level.

This paper will show that in most cases of insufficient flicker suppression, it is the harmonic power, i.e. distortion power, that was neglected and not taken into consideration while planning flicker mitigation measures.

In [1] and [2] it was shown that distortion power D is influencing flicker measurement results, and that $\Delta D$ should be taken into account when designing flicker mitigation measures.

The influence of harmonic components on flicker coefficient was detailed in [6], and experimentally proven that there is an increase in Pst due to existence of higher harmonics.

In [8] it is shown that strong and fast variations of network voltage due to transients that repeat over time are increasing Pst readings of flickermeter. This findings speak in favor of using STATCOM to compensate EAF current and its harmonics rather than SVC, due to much faster response times of STATCOM in time and frequency domain.

There are a number of authors that recognize this problem and several techniques for improved flicker control had been presented in [3], [4] and [5], all of them taking into account distortion power of the load.

In [9] it was practically measured and verified that reduction of voltage variations during EAF operation is shortening furnace tap to tap time and thus increasing furnace efficiency.

In order to achieve maximal flicker reduction rate, a high power STATCOM – active filtering system is proposed, with real time response to compensate reactive power, voltage fluctuations and dynamic harmonic distortion caused by EAF. It is shown that this technology provides superior performance for EAF flicker mitigation and full EAF grid compliance according to any know grid code for the systems where conventional

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compensator technology performance has not been able to provide satisfactory results.

## II. HARMONICS POWER FLUCTUATION

It is known that in practice many EAF operators are still experiencing serious voltage flicker levels although flicker improving equipment had been installed. Compensation of fundamental reactive power is effective in improving flicker level, but if harmonic improvement is not good enough flicker readings will still be higher than expected. Underestimating voltage flicker problem, i.e. neglecting influence of harmonic power fluctuations may lead to installation of inappropriate or insufficient flicker mitigation equipment.

Harmonic power fluctuations of EAF are important cause of voltage flicker. Therefore it is vital to take into consideration harmonic power fluctuations in order to achieve desired flicker reduction.

In practice it is common to estimate flicker reduction based on reduction of voltage fluctuations $|\Delta V| = X_S \Delta S$, where $\Delta S$ is calculated using the equation $\sqrt{P^2 + Q^2}$, P and Q being the active and reactive power of the load. This method is often underestimating impact of distortion power on voltage fluctuations as shown in [1].

Instead it is more precise to take into consideration the fluctuations of distortion power as well. If apparent power of the system is defined as in (1):

$$S = \sqrt{P_1^2 + Q_1^2 + D^2} \qquad (1)$$

where: $P1$ – active power at fundamental frequency, $Q1$ – reactive power at fundamental frequency, $D$ – distortion power, defined as in (2) and (3):

$$D = \sqrt{\sum D_n^2} \qquad (2)$$

$$D_n = V_n I_n^*, n \neq 1 \qquad (3)$$

From (4) and (5) it is seen that voltage variations are clearly influenced by harmonic power fluctuations.

$$|\Delta V| = X_S \Delta S \qquad (4)$$

$$|\Delta V| = X_S \sqrt{\Delta P^2 + \Delta Q^2 + \Delta D^2} \qquad (5)$$

where: $\Delta V$ – voltage fluctuations, $\Delta S$ – apparent power fluctuations, $X_S$ – system impedance.

The above equations show that technical solution, aiming at reaching grid code flicker limits at PCC, has to meet demands of both reactive power compensation in real-time and cancelation of harmonic power fluctuation. One such solution is presented in this paper.

## III. FLICKERMETER SUSCEPTIBILITY TO POWER FLUCTUATIONS

There are two predominant parameters used for flicker assessment. One is flicker severity Pst, i.e. Plt, a well known method defined by IEC 61000-4-15. The other is voltage flicker index $\Delta V_{10}$, predominantly used in Asia-Pacific region, defined by Central Research Institute of Electric Power Industry (CRIEPI). Methodologies used are different and results are not identical when calculated over the same input data set [10].

Both methodologies are using fast Fourier transform (FFT) for accessing voltage harmonic components. As shown in [11], in order to simplify raw data sampling, these algorithms always use truncating window with fixed sampling frequency and fixed duration according to system nominal frequency. Since the working system frequency depends on balance of load and generation, and with EAF it is a highly dynamic process, there is a fast changing deviation of system frequency from nominal value. This is causing a leakage effect that is giving an additional rise to Pst readings in case of dynamic load rich in harmonic content, that is influencing system frequency.

Paper [8] analyzed in depth the input voltage parameters variations on Pst value. It was shown that very fast changing signal, i.e. the transients typical for electric arc furnaces, might also lead to higher resulting Pst value. This finding is significant, since it proves necessity to reduce higher order transients and harmonics in order to uphold successful flicker mitigation.

Aforementioned sensitivity of flickermeter to power fluctuations, including fast changes in both fundamental and harmonic frequencies, show that very fast compensation of both reactive and distortion power is required if maximal possible reduction in Pst is desired. Such a speed of response is possible with STATCOM type of device, as described in section IV.

## IV. DESCRIPTION OF PRACTICAL EAF CASE

Main loads at the production site are 50 ton Electric Arc Furnace (EAF) and Ladle furnace (LF). Melting of the steel scrap is carried out with Electric Arc Furnace rated at 30MVA. Plant is connected to the public network and is fed from a substation located 7 km away making it a weak network. Plant is supplied by a 100 MVA transformer. Rapid fluctuations in the demand of reactive power were caused by the dynamic operation of the Electric Arc Furnace (EAF) in the steel plant. Inability of the supply grid to deliver the reactive power demand in an efficient manner were resulting in high voltage fluctuations and flicker. High flicker was also being experienced by the other customers connected to the same bus bar. Harmonic distortions were also high at the plant. As a result of poor power quality, melting time at the plants were longer and maintenance costs higher.

To achieve a maximal possible flicker reduction, instead of the Static VAr Compensator (SVC) a complete 16 MVAr Static Synchronous Compensator (STATCOM) solution was installed at PCC at 33KV bus bars. Total compensation of 16 MVAr was equally divided between active and fixed part. 8 MVAr of active compensation was provided by 6 pcs of STATCOM modules, whereas remaining 8 MVAr was provided by fixed filter capacitor banks. Continuous reactive power compensation was from 0 MVAr(Ind) to 16MVAr(cap) at 33Kv, 50Hz. However, the system is able to provide -8 MVAr(ind) and 24MVAr(cap) at 33KV 50Hz for the short term.

Control algorithm was set to control all required parameters in order to keep voltage constant in real-time, i.e. compensation of reactive power fluctuation, balanced an unbalanced EAF operation, active harmonic filtering and voltage control in real time.

## V. MEASUREMENT RESULTS

The measurements of main power quality parameters was taken an 33 kV bus bars. As per post commissioning report, the flicker reduction performance was outstanding. STATCOM reduced the flicker from 5.5-6.0 p.u. in nominal operation of the furnace to values below 1.0 p.u.. Based on experience a standard SVC solution in this case would have reached a flicker level of approximately 2.0 p.u.. The real time response of STATCOM not only met the dynamic demand created by Electric Arc Furnace operation in efficient way but also reduced the harmonic distortions significantly.

Figure 1. presents the waveforms of EAF, statcom and system current, as well as network voltage waveform. As expected from the STATCOM, the system current is free from harmonic components and in phase with voltage. There are no visible network voltage sags due to EAF operation.

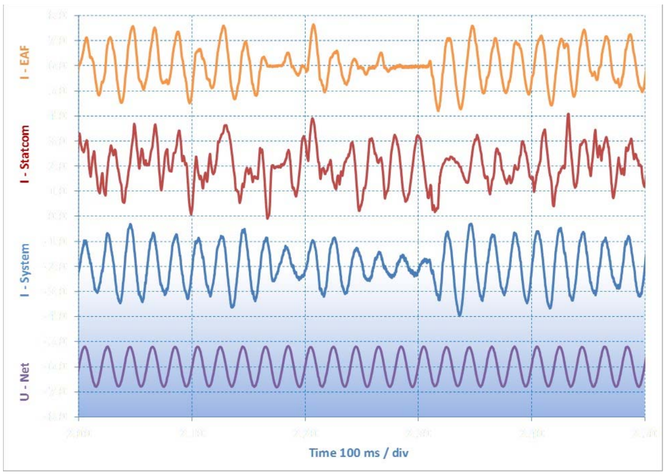

Fig. 1: Voltage and current instantaneous values (Orange – EAF current, red – STATCOM current, blue – SYSTEM current, purple – SYSTEM voltage)

Figure 2. presents a graph with comparison of harmonic current rms values of EAF and STATCOM, as well as a resulting harmonics rms of system current. The graph is scaled so that contribution of higher harmonic orders is visible, therefore fundamental current reading was cut off. It is visible that 2$^{nd}$ harmonic had the greatest contribution to current distortion, as expected from arc current. All higher harmonics experience strong reduction if not cancelation due to STATCOM operation. This will prove beneficial when it comes to final voltage flicker results, fig. 4.

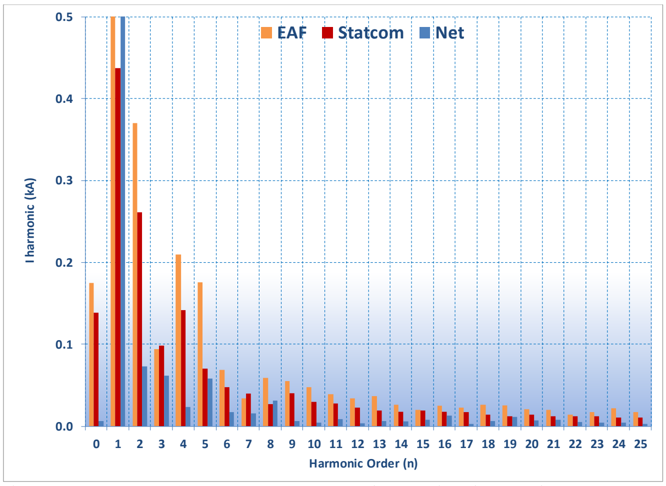

Fig. 2: Current rms (orange – EAF current harmonics [kA], red – STATCOM current harmonics [kA], blue – SYSTEM current harmonics [kA])

In Fig. 3 presented are reactive powers at fundamental frequency of EAF, STATCOM and resulting system current and voltage rms.

This figure shows that EAF reactive power peaked at 12.6 MVAr, and STATCOM had sufficient capacity to cancel it. System current and voltage have had minor oscillations due to EAF operations, which was verified by low value of Pst factor in fig. 4.

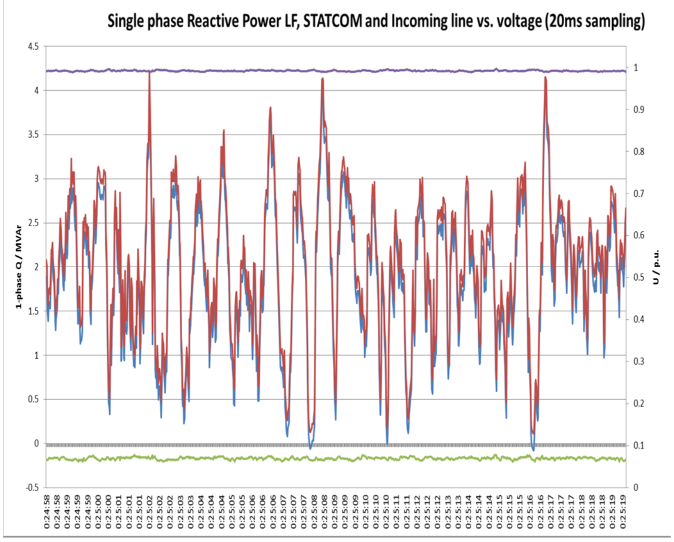

Fig. 3: Reactive power and voltage (blue – STATCOM reactive power [MVAr], red – LOAD reactive power, green – SYSTEM reactive power, purple – SYSTEM voltage [pu])

In fig. 4 there are time diagrams of line voltage Pst values. From 02:45 to 05:15 a STATCOM was operational, which is visible as reduced level of Pst. While STATCOM was not operational value of Pst was ranging from 2.0-6.0, and during most of the EAF cycle was above 4.0. While STATCOM was operational Pst was ranging from 0.3 to 1.1 and during most of the EAF cycle was between 0.5 and 1.0. Although it is not immediately visible from fig. 4., the EAF cycle was shortened while STATCOM was operational due to increased energy input into EAF. This effect is known in practice and was analyzed in greater details in [9].

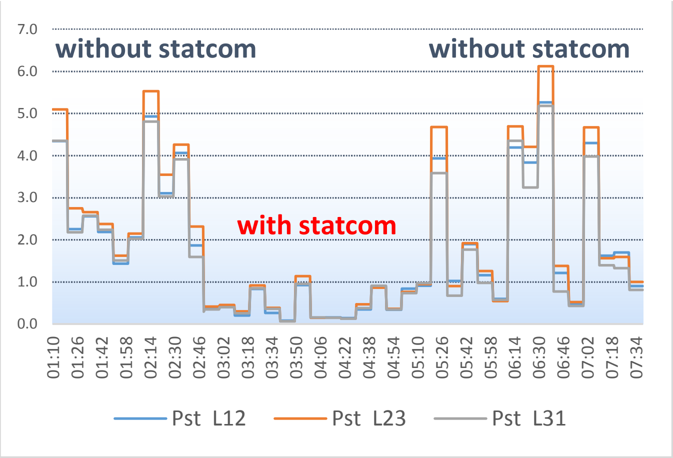

Fig. 4: System voltage flicker

It has to be underlined here that STATCOM controller was set to compensate both fundamental and harmonic frequencies, which contributed to outstanding results shown in fig. 4. The fact that the final flicker level was below grid code requirements, despite low short circuit capacity of the grid, proves that mitigation strategy presented in this paper was correct.

Such a significant reduction of voltage flicker, had a profound impact on EAF efficiency [9]. Since the voltage variations, i.e. voltage drops, had been greatly reduced, the EAF power was significantly increased. For the same working current of the furnace and for the voltage stabilized at nominal network level an energy input into the furnace charge had been increased. As a result, the melt-time has been reduced which increased revenues of the steel plant due to higher productivity. The positive connection between voltage flicker reduction and EAF productivity increase is real and present space for further investigation.

Mitigation of harmonic distortions has extended the life time of the EAF. Steel plant has also successfully met the grid codes and other customers on the same bus bar face no negative impact of the steel plant operations.

## V CONCLUSION

Securely mitigating voltage flickering of high power EAF to levels acceptable to grid operators, has always been challenging due to differences in planned and realized levels of voltage flicker. This paper states that neglecting influence of harmonic power fluctuations may lead to installation of inappropriate EAF compensation equipment, which results in flicker levels above grid code limits. To prove its point a practical case was developed on a high power EAF. In order to securely mitigate voltage flicker to an acceptable level, a solution with STATCOM device was presented, where device was set to actively cancel all needed components that are contributing to voltage flicker. Practical results show superior flicker mitigation performance, which proves the novel approach.

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