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ELECTRIC ARC FURNACE WITH STATIC VAR COMPENSATOR – PLANNING AND OPERATIONAL EXPERIENCE

Abstract

The paper describes the process of defining flicker emission limits and requirements regarding power quality of a steel plant with electric arc furnace (EAF) equipped with a static var compensator (SVC). As a first step flicker transfer factors from the point of connection to selected substations with public customers (points of common coupling) were calculated by Graz University of Technology, taking into account different grid topologies and background flicker. Planning levels, flicker targets and requirements for the SVC were defined based on those data. Using realistic flicker reduction factors and operational data of the new EAF, expected flicker values for the 110 kV grid were forecasted. After commissioning of the installation, new flicker measurements were performed to verify the calculations. Besides the description of this process, operational experience with the new equipment is given.

Keywords

Electric arc furnace; static var compensator; flicker; power quality; steel plant;

1. Introduction

Breitenfeld Edelstahl is a steel producer located in Austria and provides specialty steel ingots for the open die forging and ring rolling industry. Breitenfeld Edelstahl delivers high quality ingots into demanding end-user industries such as power generation business, oil and gas industry and the general engineering industry. Because of the huge market demand in 2007 and 2008, Breitenfeld decided to increase the production capacity from 170.000 tons per year to 250.000 tons per year. Next to investments into metallurgical equipments such as ladle furnaces, vacuum degassing units, casting and heat treatment equipments, investments into the electric supply units were necessary to achieve the requirements from the sub transmission grid operator. Due to quite low short circuit capacity of the grid, rather high flicker levels are caused by the operation of the electric arc furnace.

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2. Description of the Breitenfeld Edelstahl Operation

Breitenfeld steel plant operates a high performance electric arc furnace with a transformer rated 57 MVA. Next to the electric arc furnace Breitenfeld operates 4 ladle furnaces and two VD/VOD systems. This configuration enables Breitenfeld to produce specialty steel up to 250.000 tons per year.

The steel plant is connected to substation Mitterdorf in the Styrian 110 kV sub transmission system via a short overhead line. The plant's main 110/20 kV transformer is rated 60 MVA. This transformer supplies the 20 kV bus bar of the EAF. The EAF transformer is a 57 MVA-transformer with secondary voltage in a range from 380 V to 660 V and rated secondary current between 28 kA and 40 kA. A fixed compensation unit of approximately 5 Mvar is connected to the system as well. In Fig. 2 the layout of the electric supply system of the steel plant prior (right part) and after (left part) the investment is shown.

Fig. 1 Breitenfeld melt shop with EAF in the foreground

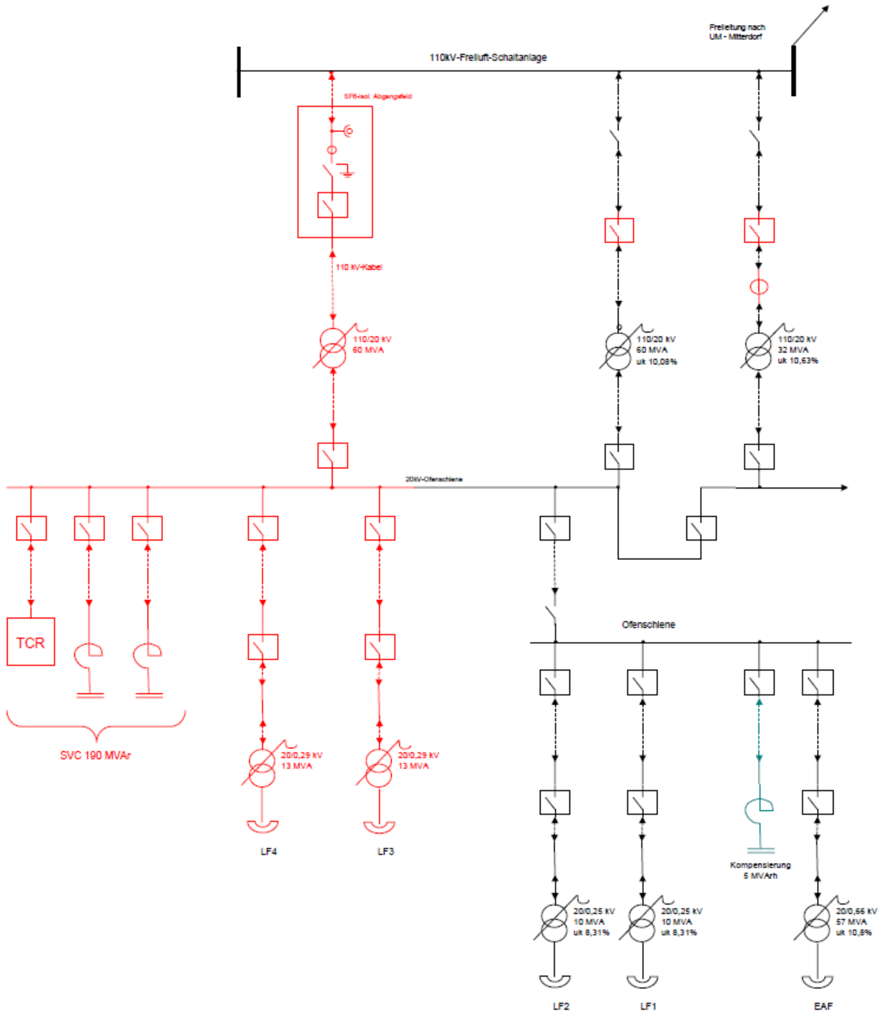

Fig. 2 Layout of the electric supply system of the steel plant prior (right part) and after (left part) investment

3. Grid Connection and Existing Flicker Problems

The Styrian 110 kV grid, to which the steel plant Breitenfeld is connected, includes 1800 km circuit length of overhead lines and 34 km underground cable. Peak demand is usually in the range of 1200 to 1450 MW. The 110 kV grid is connected to the Austrian transmission systems in seven substations, three of them located in the northern part, This northern part is characterized by a number of large industrial customers, including steel plants and pulp and paper industry. Limited short circuit capacity leads to power quality problems with flicker being the most critical power quality parameters.

It is well known that electric arc furnaces are the most powerful flicker source in electric grids. To keep the flicker values on medium and low voltage level below the limits stated in European standard EN 50160 [1], appropriate planning levels have been proposed in IEC report IEC 61000-3-7. To comply with those levels special topological measures are necessary in the grid. The double circuit line between substation Bruck and substation Ternitz is operated with split busbars, with one circuit being dedicated to industrial customers including the steel plant Breitenfeld and the other circuit being used to supply public distribution grids. With that provision the point of common coupling is transferred to substations with higher short circuit capacity, thus reducing flicker levels in the public grid to acceptable values. Fig. 3 gives an overview of the 110 kV grid in the surroundings of the steel plant.

However, the capacity of integrating fluctuating customer installations is exhausted, leaving no reserve for additional industrial customers or uprating of existing industry. Also in the case of maintenance work in the grid the switching off of circuits is not possible without operating restrictions to the steel plant.

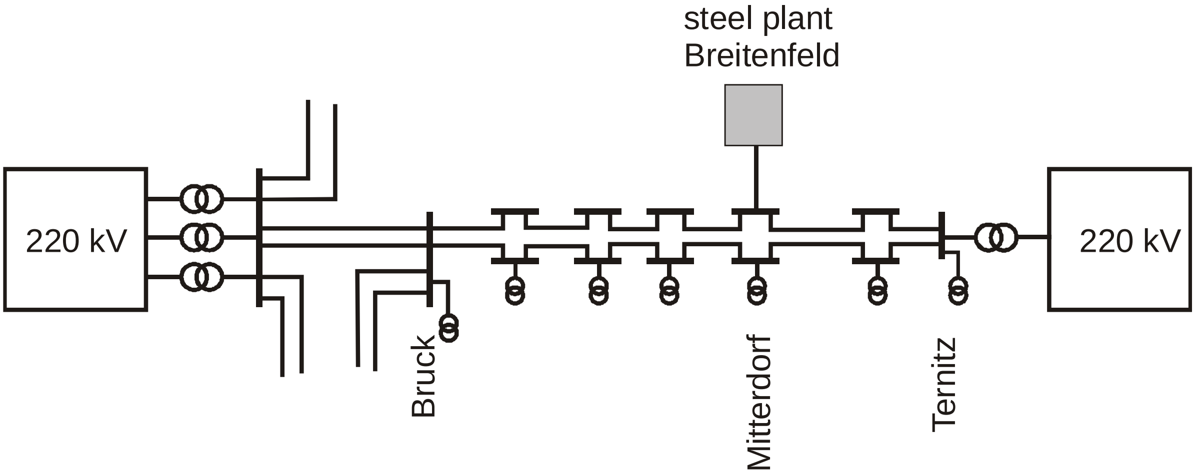

Fig. 3 Detail of 110 kV grid supplying the steel plant Breitenfeld

With that background, the application from the steel plant for an uprating of the active power caused some concern at the utility. The plan was to increase the main transformer capacity from 60 to 120 MVA and operate the furnace with maximum voltage tap 10 (660 V secondary voltage) instead of tap 8 (583 V secondary voltage).

4. Effect of steel plant uprating with and without dynamic compensation device

Graz University of Technology was asked to analyze the situation and investigate the effect of installing a static var compensator (SVC). In a first step power quality measurements in different substations were performed by the grid operator in accordance with Graz University of Technology. The aim was to document the existing situation regarding flicker level in the connection point of the steel plant and surrounding sub stations. In addition the active and reactive power consumption of the steel plant was recorded. Based on the electric data of the EAF installation and the measurements, the flicker behaviour was derived. The flicker emission P_{st} of an EAF can be approximately calculated by the ratio of the furnace's short circuit power S_{ccf} to the grid's short circuit capacity S_{cc} in the connection point, multiplied with the disturbance coefficient k_{st}.

$$P_{st} = k_{st} \frac{S_{ccf}}{S_{cc}} \tag{1}$$

According to [3], the disturbance coefficient for an uncompensated EAF would be between 48 and 85. Since real flicker measurements and the short circuit capacity of furnace and grid are available, the specific disturbance coefficient can be determined directly in the case of Breitenfeld steel plant. With a short circuit capacity of the grid of 955 MVA, a short circuit capacity of the furnace of 81,6 MVA and a flicker emission of 4,75 pu (95% quantile) the disturbance factor becomes 56. For the further analysis this factor is assumed to be constant and characteristic for the Breitenfeld EAF.

Using a short circuit based method, described in [4], the flicker transfer from the connection point of the steel plant to several sub stations in the surrounding was calculated. The flicker transfer factor k_{FX} is defined as the relation of flicker $P_{st,F}$ in a specific node F of the network, caused by a disturbing load connected thereto, and the flicker $P_{st,X}$ caused by the same load in an arbitrary node X of the network.

$$k_{FX} = \frac{P_{st,X}}{P_{st,F}} \tag{2}$$

Using correlation analysis methods, it was possible to verify the calculated flicker transfer coefficients by measurement. Of course this factor is depending on the actual system configuration respectively system switching state. In addition to the flicker emission of the steel plant, the existing background flicker $P_{st,0}$ from other customer installations must be considered. Flicker measurements with the steel plant Breitenfeld not in operation provided a good indicator for that. The summation of flicker caused by independent sources follows approximately a cubic law. So with the help of equation (1) and (2) the expected flicker level in an arbitrary node X, caused by a disturber in node F and including background flicker can be calculated by

$$P_{st,X} = \sqrt[3]{\left(k_{st} \cdot \frac{S_{ccf}}{S_{cc,F}} \cdot k_{FX}\right)^3 + P_{st,0}^3} \tag{3}$$

In a next step, the short circuit capacity of the upgraded EAF was calculated, resulting in a value of 98.2 MVA. Based on equation(1), the expected flicker emission would rise by 20% which was not acceptable for the grid operator.

Since EAFs create a huge amount of reactive power fluctuations which are the main reason for voltage fluctuation in a grid with predominant inductive impedances, fast dynamic var compensation provides an excellent solution. Two kinds of compensation equipment represent the state of the art:

- The Static Var Compensator (SVC) provides constant reactive power by fixed capacitors and variable reactive power demand by a thyristor controlled reactor. Basically the device can operate inductive and capacitive. However, in the case of EAF compensation the design of capacitors and reactors is chosen such that only capacitive operation is possible. Control of the reactor usually works individually in the three phases, enabling the possibility of balancing the total load. Capacitors are split up in separate capacitor banks, equipped with series inductances thus acting as harmonic filters. Due to the constraints in control using thyristors, the effect of flicker reduction is limited. In literature an improvement of more than 2 (meaning a flicker reduction to less than 50%) is claimed [5]. However, in the case of Breitenfeld a conservative improvement of 1.9 was chosen in accordance with a SVC manufacturer.

- The STATCOM is a voltage source converter based compensator which provides inductive and capacitive reactive power without passive components. Since the inductive operating range is not needed, usually the device works with a reactive power offset, provided by a fixed capacitor. According to literature an improvement of more than 5.3 can be achieved. In the case of Breitenfeld a conservative factor of 4 was used.

Due to the fact that the compensator stabilizes the voltage on the furnace bus bar, the furnace short circuit capacity is increased. On the other hand, the SVC or STATCOM will reduce the flicker emission. Table 1 gives an overview on expected flicker levels.

	voltage tap	furnace short circuit capacity	flicker level (95% quantile P_{st})		
			substation Mitterdorf	substation Bruck	substation Ternitz
(a) previous configuration	8	81,6 MVA	4,79 pu	1,51 pu	1,69 pu
(b) new transformer	10	98,2 MVA	5,76 pu	1,80 pu	2,02 pu
(c) new transformer and SVC	10	138,0 MVA	4,26 pu	1,36 pu	1,52 pu
(d) new transformer and STATCOM	10	138,0 MVA	2,05 pu	0,82 pu	0,87 pu
Short circuit capacity of the grid S_{cc} = 955 MVA, disturbance coefficient k_{st} = 56					

Table 1 Calculated furnace short circuit capacity and flicker levels

Actually the numbers for option (c) in Table 1 are lower than for the previous configuration. Although the values are exceeding 1 pu in the points of common coupling (substation Bruck and substation Ternitz), this alternative was recommended because of following reasons:

- Due to the stiff voltage on the 20 kV bus bar the furnace power will increase without the need to change to tap 10
- Operation with tap 10 and a stable 20 kV voltage would overload the furnace transformer and is therefore not realistic
- There is an attenuation in flicker expected from 110 kV to medium voltage
- The installation costs for a STATCOM device are significantly higher than for a SVC
- In the long run an additional 220 kV substation might solve the problem definitely

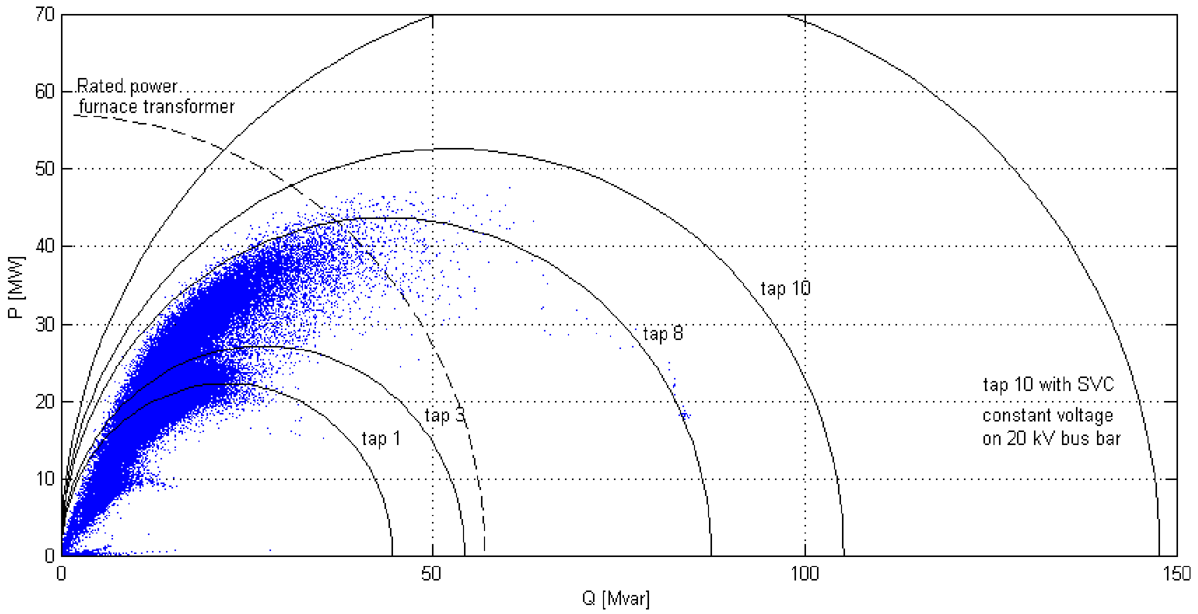

Fig. 4 Operating diagram of the EAF for different voltage taps and ideal stable 20 kV with tap 10; active and reactive power measurement included

5. Installation of SVC and Operational Experience

The SVC unit with a rated capacity of 70 Mvar was installed within the planned time of 2 month. During the installation no major problems were observed. The start up phase worked well. During the first six months of operation very few capacitors had to be changed. However the number of failing capacitors was in the expected range. The SVC is now in operation since 2009 and so far no major issues occurred with the unit. The water conditioning system has proven to be reliable and the electronic system is working without failures up to now.

So far we observed two smaller issues. One on side the cleaning of the ceramic isolators is crucial and has to be done very carefully at least once a year to avoid major damages. The second issue is that due to the solar irradiation and due to the heat exchange among capacitors, three of them already had to be changed. Due to a drift of some few µF the capacitors failed. To solve this problem a roof on top of the capacitors will be built.

From the operational point of view the steel plant operator can state that the internal 20 kV system is significantly more stable compared to the operation without SVC. Prior to the installation of the SVC voltage fluctuations in the range of ± 1.5 kV were observed. This is now reduced to approximately ± 0.1 kV.

Recent flicker measurements have shown flicker levels in substation Mitterdorf in the range of 2.4 to 2.9 pu. This is below the estimated level in Table 1, option (c) because of the following reasons:

- the furnace is not operated with voltage tap 10,
- the flicker improvement of the SVC is better than 1.9,
- the short circuit capacity of the grid is above the assumed minimum level.

Fig. 5 Capacitor bank of SVC with series inductor

6. Conclusion

High power EAFs operating in weak grids usually create unacceptable flicker emission. Uprating of a steel plant therefore needs thoroughly planning of all stakeholders. The specific furnace characteristics including furnace short circuit capacity and disturbance coefficient have to be taken into account as well as flicker transfer factors from the connection point to points of common coupling. In the presented case a classical static var compensator (SVC) proved to be the best measure to manage flicker.

Open minded cooperation of steel plant operator, grid operator and SVC manufacturer, supported by experts from university as it happened in that case can be seen as example for good practice in finding an optimum solution.

7. References

[1] EN 50160, *Voltage characteristics of electricity supplied by public distribution systems,* European standard, 2011

[2] IEC 61000-3-7, *Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems*, IEC, 2008

[3] C. Mirra, *Connection of fluctuating loads,* UIE report, 1988

[4] H. Renner, M. Sakulin, *Flicker propagation in meshed high voltage networks*, 9th International Conference on Harmonics and Quality of Power ICHQP, Orlando, October 1.-4. 2000, p1023-1028

[5] R. Grünbaum e.a. *SVC brings productivity improvements to OneSteel*, Steel Times International September 2010

[6] R. Grünbaum e.a. *Statcom for grid code compliance of a steel plant connection*, CIRED 2007, Vienna, paper 0519