Network voltage distortion by arc furnace and its mitigation

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Electric arc furnace (EAF) is the most dangerous type of load for power systems. It causes different kinds of distortion due to its frequently variable character. Nowadays there are different types of arc furnaces. This article is devoted to medium capacity EAF (with operation capacity less than 10 tons). Distortion of 6 kV power system by medium size EAF (3 tons capacity, 3.2 MVA furnace transformer) and its impact on medium voltage systems are considered and analyzed. Medium and high capacity EAFs are compared. Based on the presented experimental results it has been concluded that the main distortion of medium capacity EAF is a flicker. The values of the short-term flicker and a long-term one are 12 times higher than their permissible ones. From the viewpoint of flicker value reducing a mitigations technique is analyzed. Two ways of mitigation: static thyristor compensator and static synchronous compensator are compared for usage with medium capacity EAF. It is shown that the second way is more perspective.

Introduction

Developments in electric steel industry led to appearance of different kinds of Electric Arc Furnaces (EAF). Nowadays EAF can be sized from hundreds of kilograms to hundreds of tons; its power can be varied from 0.5 to 300 MVA (it is hard to define EAF power because it depends on operating mode and loading, but usually it can be done by furnace transformer). They have spread all over the world due to their operation flexibility, economical efficiency and ecological damage reduced level [1].

Steel melting in EAF is achieved by electric arc heating. Due to unstable and nonlinear character of arc, EAF operates with power fluctuations with different frequencies especially at the beginning of the melting process. These fluctuations cause power quality problems at all voltage levels, such as voltage sags, unbalance and flicker. The first way to avoid power quality distortion is to connect furnaces to power systems with high short-circuit power, the second way is to install var compensators or active power filters at the PCC. It becomes a mandatory practice to use var compensators with high capacity (more than 30 tons) EAFs [1], [2]. Such furnaces are a three phase ac EAFs which are main equipment of steel making plants and always are supplied via isolated line from 110-220 kV power systems. Usage of var compensators allows providing power quality in high voltage line according to the IEC standards [3].

Small and medium size EAFs are additional equipment of medium industry machinery plants. For such furnaces situation is more complex because they don't impact on high voltage grids, but make a large distortion in medium voltage systems, which are common for industry.

Distortion of 6 kV power system by medium size EAF (3 tons capacity, 3.2 MVA furnace transformer) is considered. Medium and high capacity EAFs are compared, as well as mitigations technique: static thyristor compensator and static synchronous compensator.

The main aim of this paper is selecting the main distortion of medium capacity EAF based on the presented experimental results and suggesting the perspective mitigation technique. The paper can be outlined as follows. Second section deals with a brief description of the EAF working principles and network power quality distortion caused by it. Third section examines experimental values of the power quality parameters of the network and compares them with the permissible ones. It has been concluded that the main distortion of medium capacity EAF is a flicker. In section 4 two possible technical solutions of flicker mitigation, static thyristor compensator and static synchronous compensator are presented and compared. Based on above-mentioned comparing conclusion about the perspective of static synchronous compensator for usage with medium capacity EAF has been made.

Electrical arc furnace characteristics

Principles of operation

Most common type of EAF is a three phase furnace of direct action. Such furnaces consist of ladle, electrodes and furnace transformer (Fig. 1).

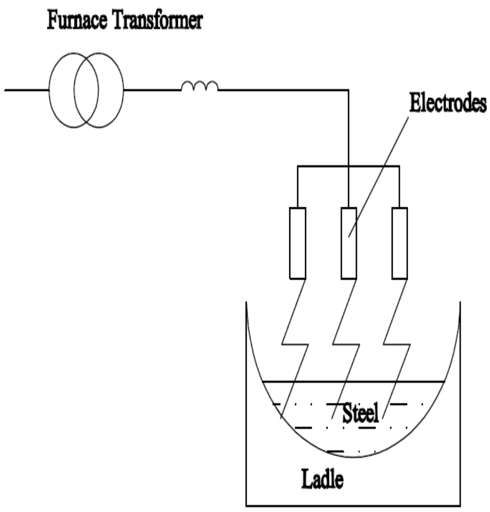

Fig. 1. Electric arc furnace structure.

Transformer is used to reduce voltage level on the arc. The value of voltage depends on the type of EAF, but usually it's less than 1000 V. Electrodes consist of graphite. In a normal mode melted steel acts as neutral point [4]. Electrode position can be regulated to control the melting process. EAF operation has a cyclical character. After the first portion of steel is being melted it must be stopped and loaded with another portion of steel.

Kinds of Distortion

Lots of articles were dedicated to power quality distortion by arc furnace [5,6]. Appropriate electrode position control and usage of series reactors can decrease EAF impact. But in any case then furnace transformer power is comparable with short circuit power of the network EAF cause further distortions:

- ·Voltage sags and swells can be caused by short circuit mode.
- ·Voltage unbalance is caused by arc breaks. A little amount of unbalance appears due to individual phase power control of EAF.
- ·Flicker is the most complicated power quality problem of EAF. Constant power fluctuations lead to voltage oscillations and associated light flicker.
- ·Harmonic distortion is caused by nonlinear characteristic of arc

Flicker is reported to be the most complicated kind of distortion caused by EAF. Flicker is a dangerous impact on human health of lighting flow fluctuations which can be associated with voltage fluctuations. Amount of voltage flicker is estimated by long term (Plt) and short term flicker (Pst). Equations and limits for Plt and Pst are determined in international standards [3], [8].

All kinds of distortions are dangerous for different sort of electrical equipment. Uncompensated reactive power flow also leads to additional power losses in the network and leads to design EAF feeder transformers with high power margin. Quantities assessment of such distortions depends on type of EAF its control system and network short-circuit power.

Reactive power compensation and voltage filtering is a very important issue to increase efficiency of power system. Moreover voltage stabilization allows increasing EAF efficiency. EAF operation time as well as consumption of electrodes can be decreased by appropriate compensation technique [7].

Example of Medium Size EAF Operations

EAF with 3 tons capacity and 3.2 MVA transformer is operated on Borodinskiy Electromechnical Plant. It is connected to a 6 kV line, which was used to be as an emergency feeder for other plant load. Plant is supplied from city substation from 110 kV power line via 25 MVA three winding power transformer. Short-circuit power at PCC is approximately 66 MVA.

Phase-to-phase voltage with 1 minute resolution at PCC during operating cycle of EAF is presented on Fig. 2.

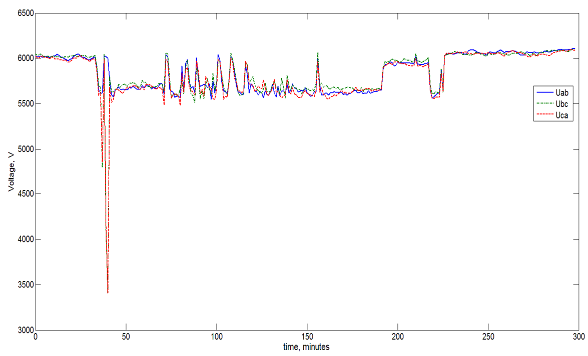

Fig. 2. Network voltage at PCC during EAF operating cycle.

In the beginning of the melting it can be seen a huge voltage sag due to the short circuit mode in EAF. It seemed that this short circuit was between B and C phases. After a certain time EAF was stopped for steel loading and started again. It can be seen by voltage oscillations with large amplitude (250 V). This process was repeated for several times with small period of about 1-2 minutes. At the end of operating cycle furnace began a boring period with lower power fluctuations.

Some small amount of voltage unbalance can be seen. The averaged values of power quality parameters are summarized in Table I. These parameters were calculated according to the Russian industrial standard, which is almost similar to IEC standards [8].

Table 1

Power quality parameters

Power Quality Parameters	Measured value	Permissible value
Power factor	0.7	0.95
Voltage sag, %	6	10
Voltage unbalance, %	1.7	2
Short term flicker, Pst	12	1.38
Long term flicker, Plt	11.4	1
THD, %	3	5

Most of all power quality parameters are lower than permissible values except the Pst and Plt, which is 12 times higher. Although peak values of voltage sags and THD were higher. Large amount of flicker for medium sized EAF can be explained by low short circuit power at PCC. Another reason is that loading period in medium capacity EAF is less than in the big one. It adds some oscillations in power system voltage.

Integration of small sized EAF in plant with medium voltage line becomes a complicated subject, because from one hand it can be supplied from existing power line and from the other hand amount of voltage fluctuations (flicker) is too large and can be dangerous for other equipment.

Ways of mitigation

The simplest and most efficient way to damp voltage oscillations is to compensate reactive power flow, because line impedance has mostly inductive character. Shunt variable reactive compensators suits well for such purpose. For EAF the most important parameter is reaction speed of compensator. From this viewpoint two well known ways of mitigation: static thyristor compensator and static synchronous compensator have to be analyzed and compared for usage with medium capacity EAF.

Static Var compensator

The first high-speed variable reactive power compensator was thyristor static var compensator (SVC) [9]. Fig. 3 shows a single line diagram for typical SVC application for EAF.

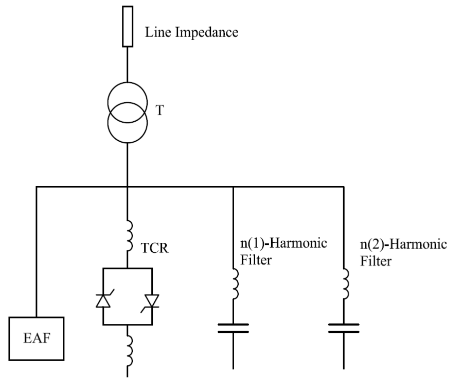

Fig. 3. SVC typical single line diagram.

SVC consists of thyristor-controlled reactor (TCR) and harmonic filters. Current in TCR can be controlled via firing angle of thyristors (Fig. 4).

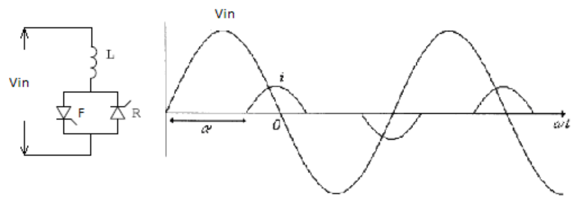

Fig. 4. TCR current control.

It allows varying SVC power in the range from 0 to nominal value. Within the firing angle decreasing TCR begins to inject high odder harmonics in the power system (5th and 7th for 6 pulse TCR).Harmonic filter consists of reactors and capacitors and allows to damp TCR current distortion, they also are tuned according to the EAF current. For the fundamental voltage component harmonic filters are reactive power sources. SVC control system make sum of TCR and harmonic filters current be equal to EAF reactive current.

SVC is widely used for high power EAF. SVC usage increase power quality at the high voltage line to permissible value. Due to low on-state resistance of thyristor and parallel connection of them allows to design SVC on high power rates. But SVC has several disadvantages [9]:

- ·SVC power depends from square of line voltage. This makes it speed decrease especially in networks with low short circuit power.

- ·SVC reaction is also limited by minimum firing angle which is quarter of voltage period.
- ·For small sized EAF required compensation power is not so big. Sometimes it's lead to TCR inductance decrease. It makes some additional requirements on thyristor because of the low current growth (di/dt) and increases losses in TCR.
- ·SVC needs a huge installation place. Air reactors require a special dangerous zone due to external magnetic field. This effect increases within TCR inductance increasing.

All this disadvantages makes SVC inefficient for small capacity EAF making its power and cost increase. Some problems with SVC installation in plant due too large installation place also occur.

STATCOM

Static synchronous compensator (STATCOM) has similar principle of operating with synchronous compensators [10]. But the key element of STATCOM is a voltage source converter (VSC). Development of IGBT leads to appearance of efficient high frequency VSC and increase of available STATCOM power.

For power less than 5 MVA a simple two level six-pulse VSC can be used (Fig. 5).

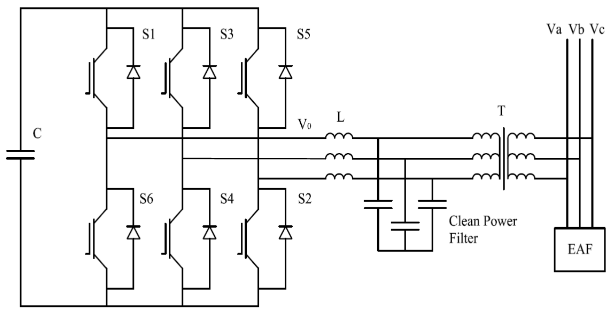

Fig. 5. STATCOM structure schema.

Such converter needs a coupling power transformer to connect it to the medium voltage grid. From dc side VSC is should be connected to capacitor and from ac through coupling reactance and clean power filter to secondary winding of power transformer.

By applying pulse-width modulation (PWM) for VSC control amplitude, frequency and phase shift of output voltage can be regulated. By single-phase vector diagrams (Fig. 6) it can be seen that STATCOM absorb reactive power then VSC output voltage is less than secondary winding transformer voltage.

Otherwise then output voltage is larger STATCOM behaves like a reactive power source. A phase shift between network and VSC output voltages leads to real power exchange. In leading mode (positive phase shift) STATCOM generates some real power and discharges its capacitor, otherwise (lagging mode) capacitor voltage increases by real power absorption [10].

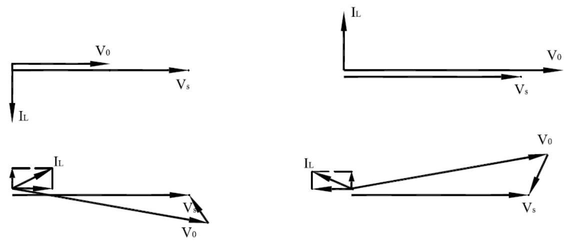

Fig. 6. Principle of power exchange in STATCOM.

In comparison with SVC STATCOM has higher losses, because of IGBT on-state resistance and additional switching losses [9]. For high power applications a multilevel converter should be implemented to decrease switching losses [10]. It leads to significant cost growth of STATCOM for high power applications.

Despite higher losses rate STATCOM is more efficient for small sized EAF compensation. High frequency PWM allows reacting immediately on voltage disturbances. STATCOM power depends linearly from power system voltage. These increase STATCOM capability to mitigate flicker especially in power systems with low short-circuit power [9]. Lack of huge harmonic filters (clean power filter consist of low power capacitor bank and iron-core reactor) and need of external reactive power sources makes STATCOM to take little installation place. These benefits make STATCOM more efficient for flicker mitigation than SVC especially for small sized EAF. STATCOM efficiency can be also increased by appropriate control system implementation.

Conclusion

Power quality distortion by EAF operation was considered. EAF is a frequently variable load with poor power factor and it causes voltage sags and swell, unbalance, harmonic distortion and flicker. Flicker is a general power quality distortion of EAF. To provide electromagnetic compatibility with other equipment and to increase EAF efficiency a reactive power compensator should be installed in parallel with EAF.

For small capacity EAF power quality measurement were provided. They showed that amount of flicker in such furnace is much higher than in huge one. It becomes because of the low short-circuit power of EAF supply power system and short loading-melting cycle of small sized EAF.

Two ways of EAF compensation technique was also considered: SVC and STATCOM. SVC is widely used for large capacity EAF, but for small sized STATCOM becomes a more efficient mean of compensation.

Future work will be devoted to application of STATCOM for small sized EAF. Due to some amount of high odder harmonics an electromagnetic compatibility (EMC) of VSC should be studied. Ability of active power exchange with appropriate dc capacitor and external supply will be also studied. An optimal control system with high reaction speed to provide permissible flicker must be developed.

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