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A Comparison between SVC and STATCOM in Flicker Mitigation of Electric Arc Furnace using Practical Recorded Data

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Abstract

Electric arc furnace (EAF) is one of the largest loads in electric power systems. It is highly time varying and nonlinear. Its reactive power variations cause voltage fluctuations in nearby system which is known as flicker. On the other hand the nonlinear voltage-current characteristic causes strong voltage and current harmonics in EAF. To this end Flexible AC Transmission Systems (FACTS) technologies are used to mitigate the flicker and harmonics caused by EAF. The mostly used FACTS device in EAFs is Static VAr compensator (SVC) which can reduce the flicker and harmonics to some levels. Delays relevant to reactive power measurement and thyristor ignition reduce compensation capabilities of SVC. In order to prevent these delays, one can use faster compensation devices. Static Synchronous Compensator (STATCOM) may be considered as a high performance candidate for this purpose due to its fast and flexible response. In this article the performance of STATCOM is compared to SVC in EAFs plants. For this purpose the system is simulated with SVC and STATCOM in PSCAD/EMTDC using the practical EAF data records. Data records are the instantaneous EAF voltage and current recorded from EAFs in Mobarakeh steel company in Esfahan/Iran.

Keywords: Electric Arc Furnace; EAF, Reactive power; Flicker, SVC, STATCOM

1. Introduction

Electric Arc Furnace (EAF) is high power industrial load which has unbalanced, non-linear and time-varying characteristics with a strongly fluctuating consumption of reactive power. The fast, stochastic large variations in reactive power required by the EAF causes voltage drops, rapid voltage variation and harmonics across the ac supply network [1]. Voltage fluctuations which is known as flicker not only have negative impact on the power system quality and other loads, but also have an effect on the arc furnace operation, power output and efficiency [2]. Flicker is an observable variation in brightness of a lamp as a result of quick fluctuations in the voltage of the power supply. The voltage drop is generated over the source impedance of the grid by the changing load current of an EAF. These fluctuations in time produce flicker [3]. The amount of flicker depends on the size of the EAF in relation to the short circuit power of the grid at the point of common coupling [4].

Since the EAF does not have any built-in compensation for regulating voltage variations like an electrical motor or drive system, which consumes more current when voltage drops so that sustain the same torque, the power input to the furnace is very sensitive to flicker and because of nonlinear voltage-current characteristic of an EAF, efficient operation of an EAF requires the voltage to be kept high and stable [5].

Because of the reasons that mentioned before, Flexible AC Transmission Systems (FACTS) technologies are used to mitigate the flicker and harmonics caused by EAF [6]. The FACTS device that commonly be used in EAFs is Static VAr compensator (SVC) which can reduce the flicker and harmonics to some levels. By installing an SVC on the furnace busbar to instantaneously compensate the furnace’s large and continuously varying reactive power demand, troublesome voltage drops and fluctuations can be avoided. The mean power input to the arc furnace is raised, and nearby electrical equipment can operate as usual. However, it cannot do its compensation task very well because of delays relevant to reactive power measurement and thyristor ignition [7]. Static Synchronous Compensator (STATCOM) is a high performance candidate for SVC in compensating the undesirable characteristics of an EAF [8].The response time of a STATCOM is shorter than that of an SVC, mostly by reason of the fast switching times provided by the IGBTs. STATCOM is based on high frequency switching voltage-source converter (VSC) while SVC performs as a controlled reactive admittance. STATCOM functions as a synchronous voltage source. STATCOM has better characteristics than SVC. When flicker happens, it forces the STATCOM output current to its ceiling; its maximum reactive output current will not be affected by the voltage magnitude. Therefore, it exhibits constant current characteristics when the voltage is low under the limit. In contrast the SVC's reactive output is proportional to the square of the voltage magnitude. This makes the provided reactive power decrease rapidly when voltage decreases, thus reducing its stability.

In this paper the performance of STATCOM is compared to SVC in EAFs plants. Simulation studies are done for this purpose in PSCAD by using practical instantaneous EAF voltage and current data records that gathered from EAFs in Mobarakeh Steel Company (MSC) in Esfahan/Iran.

It is shown that Flicker Mitigation of EAF in case which equipped with the STATCOM is better than the case equipped with SVC; however, in comparison with SVC these devices are much more expensive.

1. Basic principles of svc

The SVC is a mature and reliable technology which consisted of two main types: TCR and TSC. A TCR (Thyristor Controlled Reactor) consists of a reactance connected in series with a pair of thyristors and it is the most-widely used practical realization of a variable reactance. TCRs can be used with Fixed Capacitors (FCs) which can cover variety of variable reactances. TSC (Thyristor Switched Capacitor**)** consists of a power capacitor connected in series with a bidirectional thristor valve and, usually, a current limiting reactor (inductor). TSCs are often used conjunction with TCRs. Figure 1 shows the SVC types.

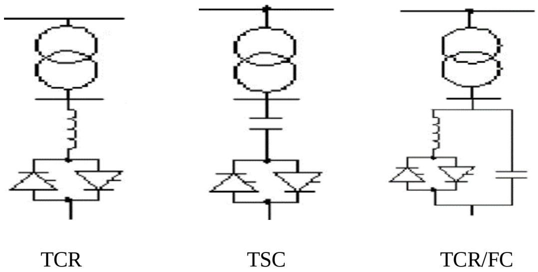

Fig. 1. Types of SVC

SVCs have been used mostly in industrial and transmission applications [9].

In transmission applications, the SVC is used to control the grid voltage. If the power system's reactive load is capacitive (leading), the SVC will use TCRs to absorb VArs from the system, lowering the system voltage. Under inductive (lagging) situations, the capacitor banks are automatically switched in, thus providing a higher system voltage. By connecting the TCR, which is continuously variable, along with a capacitor bank step, the net result is continuously-variable leading or lagging power. In industrial applications, SVCs are typically placed near high and rapidly varying loads, such as EAFs, where they can smooth flicker voltage [10].

A widely used method for flicker reduction in EAF is to use SVCs. The SVC can also keep power factor in higher levels at the PCC, independently of the reactive power fluctuations from the furnace loads, and filter the harmonics generated by the furnace [11].The maximum useful MVAr size of the SVC would generally be the maximum VArs drawn by the furnace system [12].

SVC can improve system power quality, and also increase EAF productivity and provide additional economic benefits. However, it cannot react to the fast-varying flicker very well with the inherent limit of relatively low-bandwidth and hence its dynamic performance for flicker mitigation is limited

2. Basic principles of STATCOM

A static synchronous compensator (STATCOM) is based on a solid state synchronous voltage source which generates a balanced set of three sinusoidal voltages at the fundamental frequency with rapidly controllable amplitude and phase angle. Basically it consists of a voltage source converter, a coupling transformer, inductive filter and a dc capacitor (Figure 2).

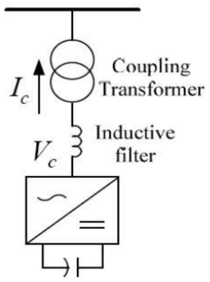

Fig. 2. Basic structure of STATCOM

Control of the reactive current and hence the susceptance presented to power system is possible by variation of the magnitude of output voltage with respect to bus voltage and thus operating the STATCOM in inductive region or capacitive region. By appropriately controlling the STATCOM voltage source, any desired current can be forced to flow through the tie reactance. The voltage-source inverter based STATCOM is appropriately designed with high band width control capability, then it can be used to force three phase currents of arbitrary wave shape through the tie inductance into the power line. This unique capability makes the STATCOM an ideal candidate for EAF compensation. Connected to the ac supply bus for an EAF, the STATCOM can thus be made to supply those components of the arc furnace load comprising non-sinusoidal, unbalanced, randomly fluctuating currents, in addition to the fundamental reactive power. The STATCOM will normally not have a source of real power connected to its DC terminals. It is therefore unable to supply sustained real power or real power fluctuations. With suitable choice of DC capacitor, however, it is capable of supplying in large part the fluctuating real power requirement of the EAF [13]. STATCOM can be considered as a synchronous condenser with a very low delay time [14].

3. Data Records

Actual input voltage and current waveform data was recorded from eight EAFs installed in MSC.

This plant contains EAFs rated at 70 MW. Power system frequency is 50 Hz. The arc furnace transformers have the following ratings: 90-108 MVA, 63kV/230-720V Y/Δ with x=6.5% based on voltage 720V. Supplying transformers of the plant are two three-phase, three-winding transformer banks rated at: 220/220/110 MVA, 400(Y)/63(Y)/33(Δ) kV. The arc furnaces are compensated by a SVC consisting of thyristor controlled reactors (TCRs) and fixed capacitors (FCs). The SVC and second, third, fourth and fifth harmonic filters have been connected to the tertiary winding of the supplying transformers. Single line diagram of the EAFs in MSC is shown in figure 3.

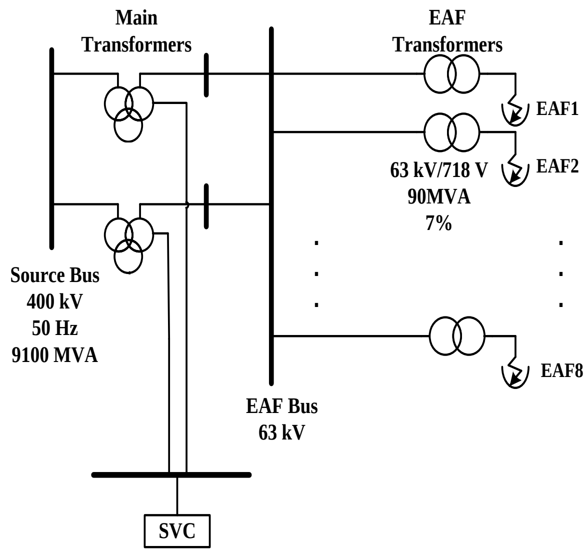

Fig. 3. Single line diagram of EAFs in Mobarakeh steel company system

Data for eight EAFs including three-phase supply voltages and currents, measured in the primary side of EAF was collected. Data records cover 100 seconds of real time furnace operation with sampling time equal to 128 μs.

4. Flicker Meter

Flicker is one of the major power quality disturbances in power systems. It originates from the fast load variations, such as EAFs, motors, rolling mills, mash welders, and electric welders [15]. It can cause voltage fluctuations that may result in flickering the light of the fluorescent and incandescent lamp with an uncomfortable feeling. The voltage flicker is characterized by variation of voltage magnitude in the range of 10% of nominal voltage and with frequencies between 0.2 to 30 Hz [16].

Voltage flicker is the main disturbance and disadvantageous effect caused by EAFs to the power supply system. The procedure of how voltage flicker happened in EAF is as follows: beginning of an EAF heating cycle involves introducing the electrodes into the scrap steel to start the melting process. The arc established at this time is very unstable, and the electrodes are short circuited by the scrap metal at times. During the melting period the arc length changes as a result of the electromagnetic force and the continuous movement of the molten pool.

The power into the furnace is mostly reactive, with large swings in furnace current between short-circuit levels to near zero. This can cause severe voltage flicker in the connected utility power system [17]. Spectral analysis confirms that lamp flicker caused by EAF action is severe around frequencies

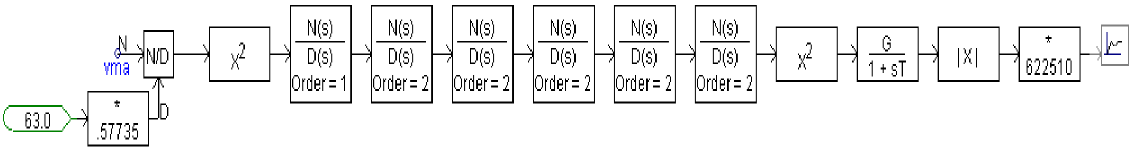

Fig. 4. Procedure of calculation the voltage flicker

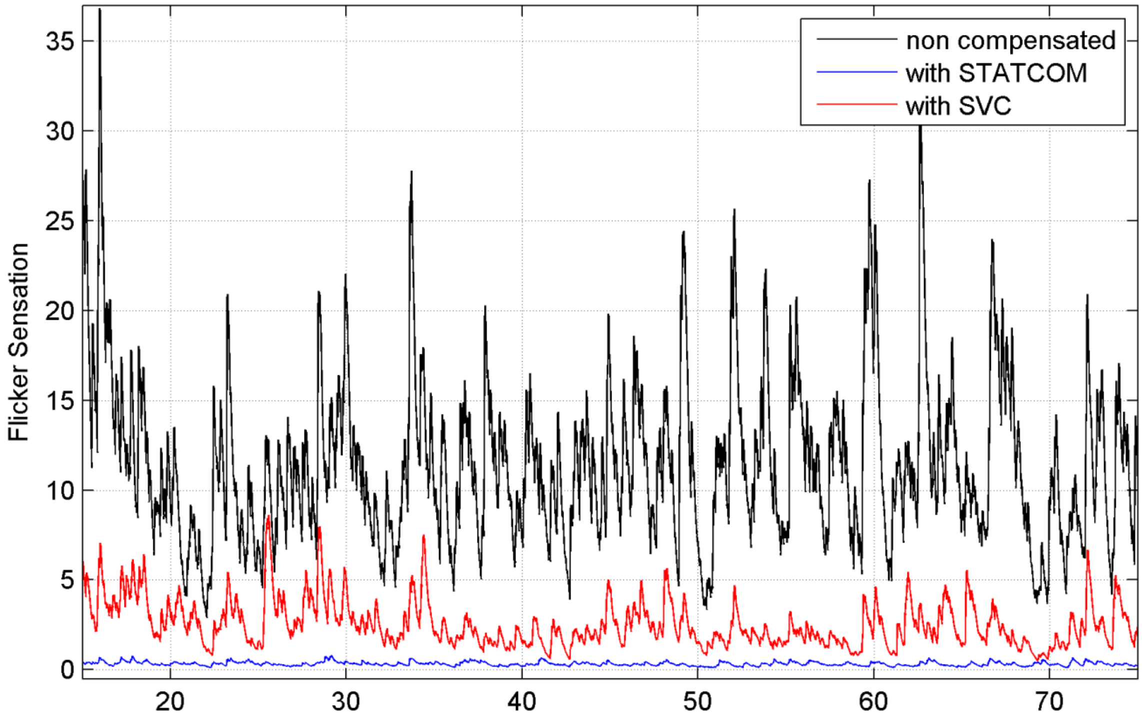

Fig. 5. Voltage flicker of EAF bus (63kV)

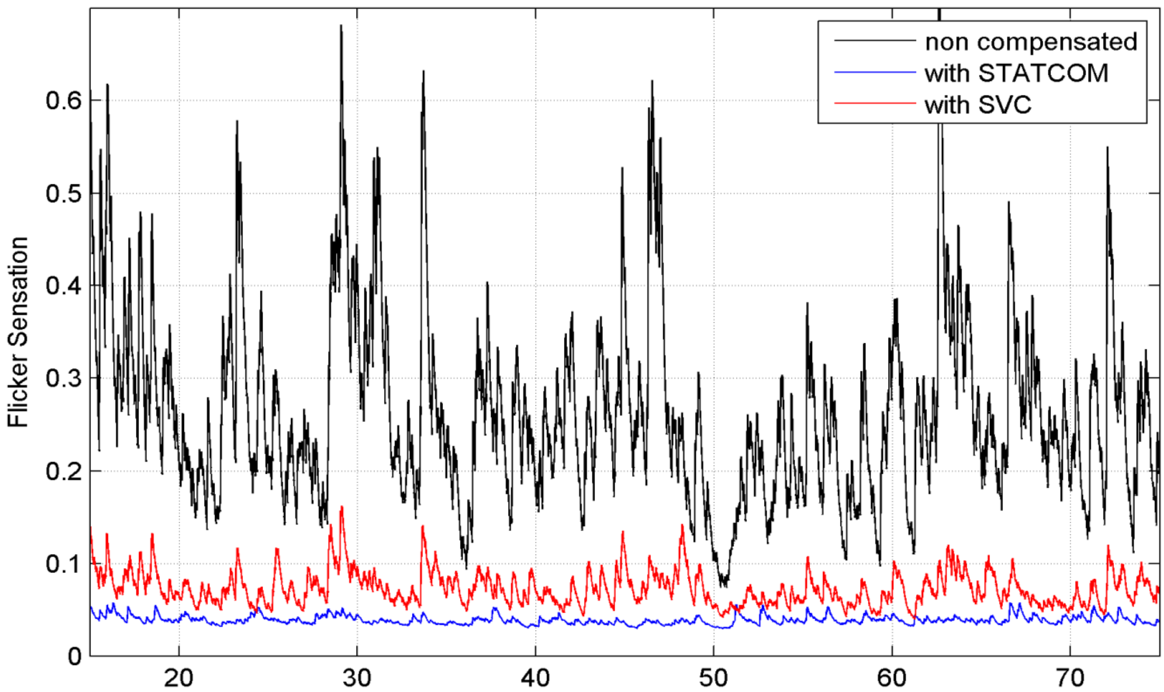

Fig. 6. Voltage flicker of Source bus (400 kV)

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for which the human eye is particularly sensitive, reaching a maximum corresponding to a frequency of 8.8 Hz. The amount of flicker depends on the size of the EAF in relation to the short circuit power of the grid at the PCC [18].

To be able to measure the level of flicker, a meter is needed. There are different standards existing describing flicker meters. The flicker meter used in this paper is the one implemented by PSCAD. The procedure of calculation is shown in figure 4. For the purpose this paper which is comparison between STATCOM and SVC in flicker mitigation of EAF, voltage flicker is measured at 63kV bus and 400kV bus.

5. Simulation And Results

As previously mentioned EAF has strong and stochastically fluctuating reactive power consumption, which, unless remedied, will lead to voltage fluctuations and flicker, spreading over the power grid to the facilities of other consumers. When the SVC or STATCOM is on, the reactive power exchange between EAF and the utility is decreased. And as a result, the voltage flicker is reduced.

Conventional SVCs have disadvantages such as relatively long response time and the possibility to only compensate for the fundamental frequency reactive current of the load. This limits the possibilities to reduce flicker with an SVC. The response time of a STATCOM is shorter than that of an SVC, mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage.

Flicker sensation is shown in Figures 5 and 6 for 63 kV and 400 kV busses. A significant reduction in flicker is seen in case of using STATCOM in comparison with no compensation and using SVC for compensation.

This can be easily justified noting that the bandwidth of STATCOM control system is far better than that of the SVC control. It is worth pointing out that the SVC controller command can only be updated every half cycle of the system frequency. The controller command of STATCOM can be updated with frequencies of, at least, 1 kHz looking at realistic devices. However, the control system of STATCOM is more complicated than that of a SVC.

6. Conclusion

This paper has compared the performance of SVC and STATCOM for compensation of flicker caused by EAFs. The comparison has been carried out using actual records taken from instantaneous EAF voltage and current recorded from EAFs in Mobarakeh steel company in Esfahan/Iran to simulate the EAF performance. It is clear from the results that STATCOM is better than a SVC for flicker compensation; however, in comparison with SVC these devices are much more expensive Voltage flicker is fluctuating when it is non-compensated, when EAF compensated with SVC these oscillations is reduced and with STATCOM voltage flicker is a smooth one. Bandwidth of STATCOM control system is far better than that of the SVC control, and also STATCOM has better characteristics when flicker happens than a SVC.

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