Power Quality Improvement in Electric Arc Furnace

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Abstract— **Electric arc furnaces (EAFs) are the worst offending loads which pollutes the power quality. But AC arc furnace is a industrial load having variation with respect to time and is nonlinear which can cause many problems to the power system quality, including voltage dips, harmonic distortion, unbalance loads and flicker. Electric Arc Furnaces are used in steel plants for producing high quality steel. Modelling of the electric arc furnace with all its features is accomplished using a technique developed based on CAVIAR Software. It is demonstrated in this paper that SVC gives the best performance of all possible solutions. The design aspects of SVC and Filters for the EAF to improve the voltage profile of the system at the point of common coupling are discussed in this paper.**

Keywords— **EAF, TCR, Passive Filters, CAVIAR software.**

1. INTRODUCTION

The use of EAF for making steel has grown rapidly over the two decades. Presently EAF accounts for 50% of steel produced. The cycle starts with the charging of the furnace with the scrap. After the furnace is charged and the roof is in place, the operator lowers the electrode. Current is initiated and the electrodes bore into through the scrap to form a pool of liquid metal. The largest industrial loads of present days are the EAFs which causes fast and major disturbances at the bus voltage. Morever, the EAFs cause deteriorating of power quality, causing voltage flicker, unbalance in voltages and currents, and occurring of odd and even harmonics in power systems. In order to improve the above mentioned factors a SVC is designed which reduces the voltage flickering, improves power factor of the Furnace and also provides compensation of Q. The SVC is combination of TCR which is connected in delta and Fixed capacitors connected in star .The TCR is called the heart of the SVC as its function is to reduce the voltage flicker of the system. As SVC is a shunt compensation so, it is always connected in parallel to the system. The Harmonic generated by the system is eliminated by the use of passive filters. From the analysis the 2,3,4,5 order harmonics are predominant in the system.Different types of filters are designed to eliminate these predominant harmonics.

2. STUDIED NETWORK

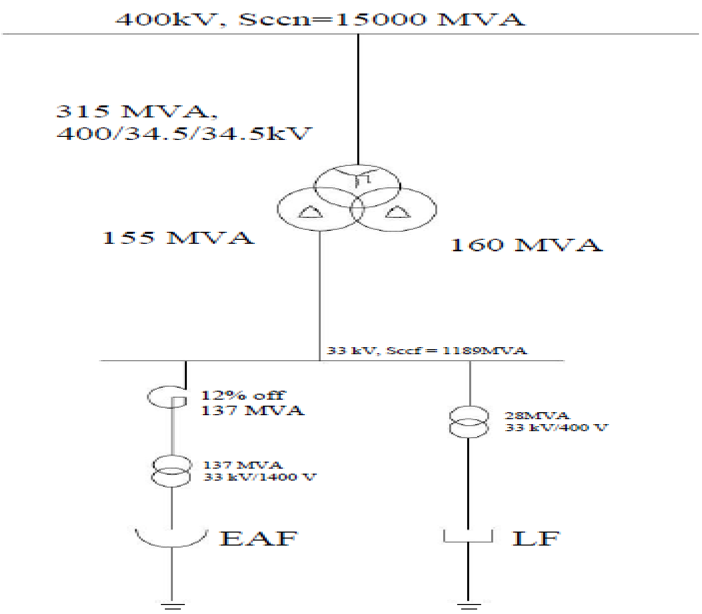


Fig.no.1 Single line diagram of studied network

Loads at the 33 kV bus

Electric Arc Furnace (EAF):

Rated capacity	137MVA
Power factor	0.65
Number of furnaces	1

Ladle Furnace (LF):

Rated capacity per furnace	28MVA
Power factor	0.78
Number of furnaces	1

SVC equipment:

TCR rating	180MVAr
Filter overall rating	180MVAr

3.REACTIVE POWER BALANCE

Depending on the fluctuation in the furnace power consumption the reactive power consumption will be higher than the mean value such as:

Qmax=Qmean+Qdyn

The dynamic fluctuation can be described as a fraction of the mean value.

Qdyn= k x Qmean

The "k" factor will vary depending number of different circumstances, e.g. type of furnace, mode of operation (melting/refining), furnace power factor etc. Very extreme conditions,such as the first minutes in a charge will have higher reactive power fluctuations from the furnace.
See figure below for clarification of the reactive power swing.

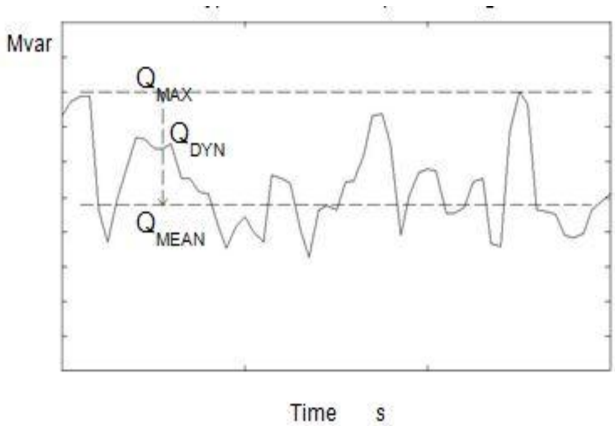


Fig.no.2 Typical EAF reactive power swing

In order to compensate the reactive power demand the SVC is rated with a continuous control range between 0 to + 180 Mvar, which will stabilize the voltage, reduce the flicker at PCC and secure that the
Power factor cosfi>0.99 @ 33kv-side can be obtained.

4.HARMONIC GENERATION AND FILTERING

4.1 Furnace harmonic generation

The harmonic generation at PCC from the EAF and LF used in the design are according to Table given below

HARMONIC ORDER	EAF HARMONIC CURRENT (%)	LF HARMONIC CURRENT (%)
2	7.4	3.5
3	17.6	7.0
4	4.5	2.0
5	10.7	5.0
6	5.1	-
7	2.0	1.0
8	1.2	-
9	1.3	-
10	0.6	-
11	0.8	0.5
12	0.4	-
13	0.5	0.3

4.2 Harmonic generation from TCR

In addition to the harmonics generated by the furnaces the harmonics from the SVC thyristor valve have to be considered. The technique of controlling the conduction intervals of the reactors generates harmonic currents which are a function of the control angle. Table below shows the maximum percent harmonic generation of the fundamental current.

HARMONIC ORDER	TCR HARMONIC CURRENT(%)
3	7.5
5	5.0
7	2.6
9	1.2
11	1.0
13	0.7
15	0.5

4.3 Filter design

The harmonic filters are chosen in order to meet the harmonic distortion requirements, generate reactive power and minimize any risk of dangerous parallel resonance. With the total harmonic generation in mind, it is important to tune and rate the needed filters, ensuring, that for no situations, a resonance mode will be hit. Final filter ratings are selected from extensive computer simulations. The number of different filter configurations is checked to identify the best possible configuration in respect to THD, individual harmonics, system resonances, degraded operation modes, etc. See selected harmonic filter data from computer simulations in Table listed below. In order to reach the SVC operation range a total filter power of 180 Mvar is installed. The best use of the total reactive power for filtering purpose is to divide the total reactive power into four different filters tuned to 2nd, 3rd, 4th and 5th harmonics. By introducing damping in the 2nd harmonic filter the problems with the inter harmonics and resonances will be mastered.

TUNING FACTOR	NOMINAL RATING MVAr	QUALITY FACTOR
1.95	50	15
2.95	60	-
3.90	40	-
4.90	30	-

5.MAIN COMPONENT RATING

This part of the report establishes the design parameters for the main components for the SVC

5.1 TCR

The TCR is connected to the 33 kV bus. The TCR reactors are connected in a delta configuration. Nominal rating of the TCR is 180 Mvar at 1.0 p.u. voltage.
That gives:

Xind= 33^2/180 =6.05 Ω

The TCR is chosen be controlled to maximum alpha = 99 at nominal power.

At alpha = 99 the Irms = 0.8 p.u.:

Xindy = 0.8 * 6.05 Ω = 4.84 Ω

Lindy1=Xindy1/□ =4.84/(2*π*50) = 0.0154Mh
The reactors are delta connected.

Lindd = 3*Lindy1 = 3*15.4 mH = 46.2 mH

Rated TCR reactor inductance : 46.2 mH/phase
Rated reactor tolerance: -2 to 0 %

5.1.1 The current rating

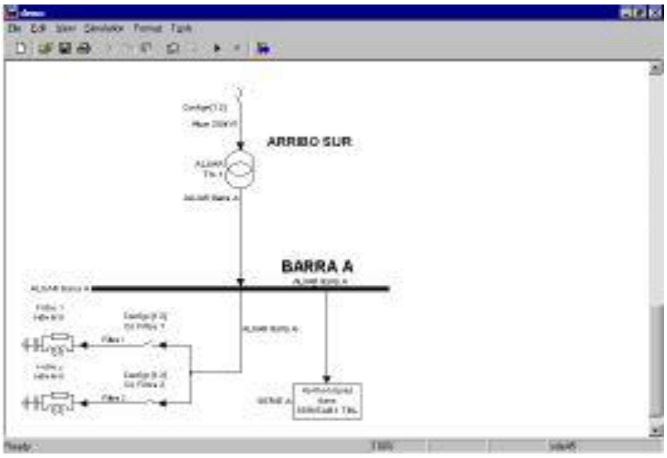
At 180 Mvar reactive power consumption, the current in the TCR reactors will be

In = 180/(3*33) = 1818 A

The reactors must be able to consume the reactive power generated by the harmonic filters at 1.1 p.u. The filters can generate 1.03 p.u. higher current due to tolerances
.
Imax continous = 1.1*1.03*1818 = 2060 A

Maximum reactor fundamental current is limited by a current limit setting at 2060 A. However the short time overload corresponds to 2273 A or 225 Mvar. This is a current limit which will follow the time-constant of the TCR coils. The current will ramp down to maximum allowed 2060 A.

5.2 Harmonic study
CAVIAR developed by power conversion is used for filter design. It calculates harmonic voltages and currents, impedances and amplification on the different voltage busbars of the network.



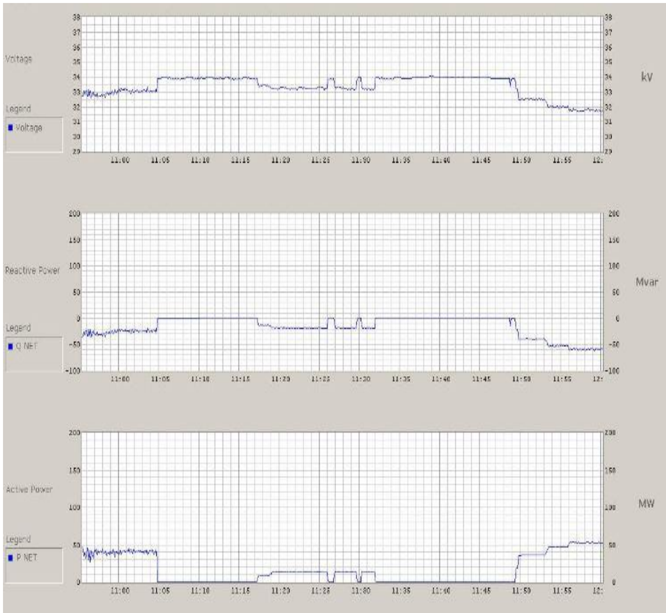
5.3 Filter design
A **Filter Circuit** is a tuned circuit, which consists of capacitor banks (capacitance) and tuned reactor coils (inductance) connected in series. Filter circuits will reduce the negative influence of the loads like
• harmonic distortion and
• poor power factor.

Careful choice of the tuning frequencies of the filter circuits with respect to the generated harmonic frequencies and amplitudes will reduce the harmonic levels.
The values obtained below in table from the simulation using CAVIAR (Matlab tool) are all per phase quantity values**.**

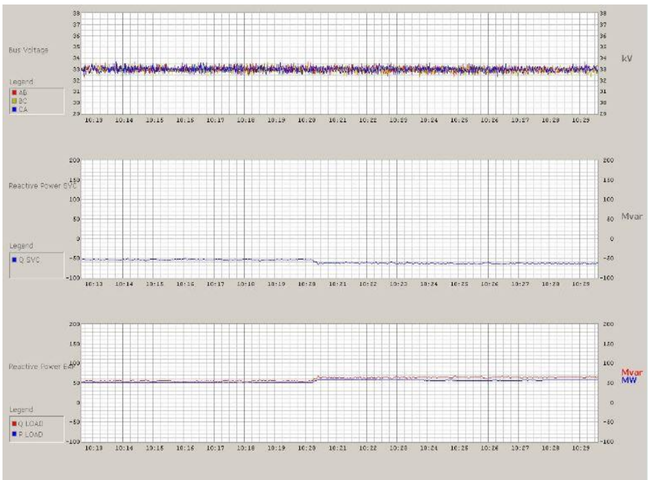
parameter	n	TUNING REACTOR	CAPACITOR BANK
2^{ND}	1.95	24.74mH	409.6microF
3^{rd}	2.95	7.50mH	155.2microF
4^{th}	3.90	6.009mH	109.2microF
5^{th}	4.90	5.022mH	81microF

6.SIMULATION RESULTS

6.1 Net bus voltage without SVC



6.2 Net bus voltage with SVC



6.3 Results for given melt profile

Stage	Start	Melt	Refine
MV system(Ω)	1.07	1.07	1.07
Furnace reactor(Ω)	1.6	1.6	1.6
Furnace transformer(Ω)	1.15	0.77	1.07
Total impedance (Ω)	9.03	6.29	8.21
Sccf(MVA)	132	189	145
THD(%)	0.8	0.9	0.9

6.4 Results for operation including SVC

Stage	Start	Melt	Refine
Total impedence (Ω)	7.96	5.22	7.14
Sccf with SVC	150	228	167
Uncompensated pst	4.86	7.41	5.42
Compensated pst	3.0	4.6	3.4
THD (%)	0.4	0.45	0.45
Furnace transformer (Ω)	1.10	0.75	1.05

7.CONCLUSION

1.With a SVC of 180MVAr (HFPFC =180MVAr and TCR = 180MVAr),we can reach the following performances on the *33 kV TCR Switching Station bus bar (PCC) :*
1. Pst ≤ 6
2.PF ≥ 0.99
3.THDu ≤ 5% individual harmonic voltage ≤ 3% (conform to norm IEEE519)
4.THDi = 8% (not conform to norm IEEE519 : 5%)
5. individual harmonic current 95% :
1. Ih2= 6% (not conform to norm IEEE519 : 1%)
2.Ih3= 5% (not conform to norm IEEE519 : 4%)
3.Ih4= 2% (not conform to norm IEEE519 : 1%)
4. For h>4, Ih (conform to norm IEEE519)

2.With a SVC of 180MVAr(HFPFC =180MVAr and TCR = 180MVAR), without pre-existing
harmonics we can reach the following performances on the *400kV MSDS Main Substation bus bar :*
1.Pst ≤ 0.84
2. individual harmonic voltage ≤1% (conform to norm IEEE519)
3.THDi = 8% (not conform to norm IEEE519 : 3.75%)
4.individual harmonic current 95% :
1.Ih2= 6% (not conform to norm IEEE519 : 0.75%)
2.Ih3= 5% (not conform to norm IEEE519 : 3%)
3. Ih4= 2% (not conform to norm IEEE519 : 0.75%)
4.For h>4, Ih (conform to norm IEEE519)

The installation of compensator is for the reduction of network disturbances and power factor correction . The SVC is dynamically controllable from 0 -180MVAr reactive power . As we can see from the results obtained with SVC ,the THD of the system is reduced to nearly half of the value obtained when the system is operated without SVC.Hence the design obtained from the simulation are best suitated for improving the power quality of the electric arc furnace .

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