A Study on the Harmonics Effect of SVC in Electric Arc Furnace Loads

Kyung-Chul Kim* · Seong-Eun Jin

Abstract

Large steel industries have time-varying nonlinear loads such as electric arc furnaces. These nonlinear loads generate harmonic currents and create distortions on the sinusoidal voltage of the power system. The main objective of the static var compensator is to maintain the rms voltage at the point of common coupling within the limit. In this research, harmonic mitigation studies were conducted with and without the SVC, and time-varying harmonics were evaluated according to the international harmonic standards (IEC 61000-3-6 and IEEE Std. 519) using a cumulative probabilistic approach.

Key Words : Electric arc furnace, Time-varying harmonics, Static var compensator, IEC 61000-3-6, IEEE Std. 519, Cumulative probability

1. Introduction

Since iron works consist mainly of electric facilities having non-linear load such as the electric furnace, they can basically be regarded as high-frequency generating sources.

Also since the characteristics of the load rapidly change to that of an electric furnace, the harmonics is generated with the variable of time, and it does not include the harmonics having odd difference but also even difference of harmonics much[1].

The accurate and confidential measurement and estimation of the source of harmonics not only prevent trouble and malfunction with the electric power system but also set the role and responsibility between the accommodation side and the electric power supplier through the POC (Point of Common Coupling).

The accommodation side must emit a harmonic current within the range allocated to sustain the quality of the electric power system beyond a certain level, whereas the electricity power supplier should maintain the harmonics voltage at the POC below a certain level.

The present study measured and assessed, according to international standards, the harmonics of the electric furnace's load in function of time. The improvement effect of the harmonics was studied by measuring the harmonics before and after the SVC (Static Var Compensator) was thrown in.

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2. Harmonics measurement

2.1 The system

Figure 1 is an example of a single line wiring diagram used for the accommodation side during the study. The substation was 0.0018+j0.0167[pu] on the base of supplying voltage 154[kV], the capacity of the short circuit was 5954[MVA], the impedance of the short circuit was 100[MVA], and the impedance of the transmission line was 0.5184+j3.4641[Ω]. The accommodation side had three main transformer units (#1 MTR for power load 95[MVA], along with #2 MTR, and #3 MTR 95[MVA]×2 for electric furnace and for roller machine). The voltage of each transformer was 154/22.9[kV] and the impedance 11.5 [%]. The SVC consisted of the 90[MVAR] of TCR (Thyristor Controlled Reactor), and four harmonics filters (second, third, fourth and fifth) total 90[MVAR].

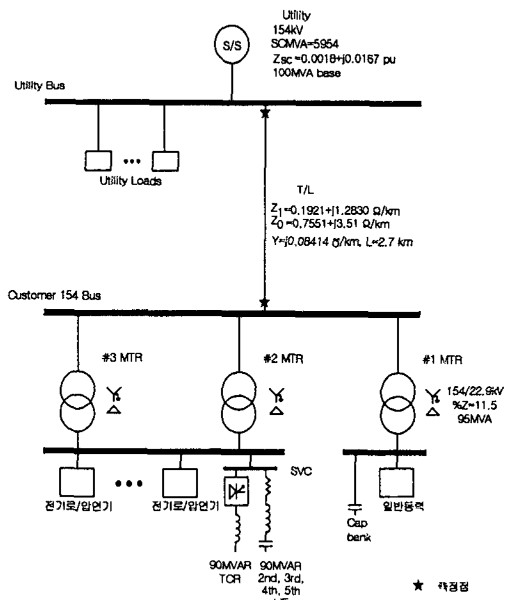


Fig. 1. One-line diagram of the case study system

2.2 Measurement instruments

The measurement and assessment of the harmonics were carried out at the point meeting of the power supplying company and the accommodator, such as the point of common coupling, which became the mother line to the customer for the showcase study.

The harmonics was measured for three seconds according to IEC 61000-4-7[2], and it was used for understanding the impact on electric facility or malfunction. The harmonics is recommended to be used in analysing long term impacts on electric facility, damage by fire and life reduction.

As the instrument used for measuring the harmonics was PNA-2010[3], 12 cycles of measurement in 36 cycles interval (one measurement every 0.8 second) was adopted.

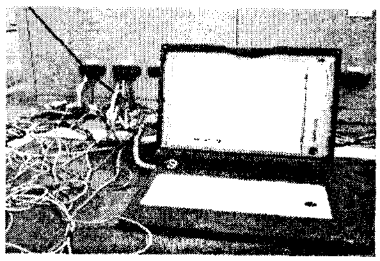


Fig. 2. Measuring equipment

2.3 Harmonics measurement before the SVC

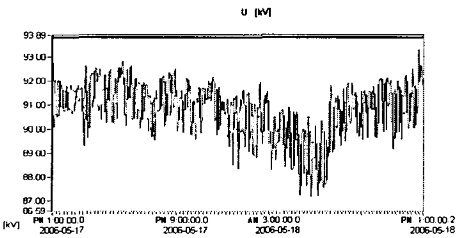
Since 1970, the SVC has been widely used as the mean to mitigate the flicker. The SVC is install to compensate the reactive electric power faster and precisely on the load of the electric furnace, to maintain constant the voltage of the mother line and to mitigate the flicker. The filter of the harmonics provides the true phase of the reactive electric power except the role to decrease the harmonics [4-6].

In table 1 are the data measured by the PNA-2010 instrument when the SVC was isolated for 24 hours.

Table 1. Measured data without SVC

	A phase (mean)	B phase (mean)	C phase (mean)
Voltage[kV]	159.1	159.6	159.8
Current[kA]	0.30	0.32	0.33
harmonic distortion of voltage[%]	0.583	0.603	0.645
Harmonic distortion of current[%]	4.193	4.284	4.123
Valid electric power[GW]	0.026	0.029	0.026
Outward electric power[GVA]	0.027	0.031	0.028

Figure 3 shows only A phase for convenience as the virtual value and THD (Total Harmonic Distortion) of the voltage measured for 24 hours by the PNA-2010 instrument.



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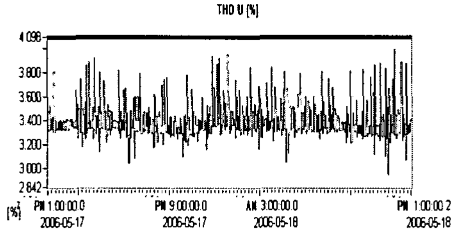

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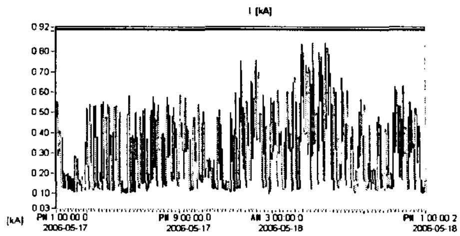
Fig. 3. Measured voltage magnitude and THD time trends of phase A(without SVC)



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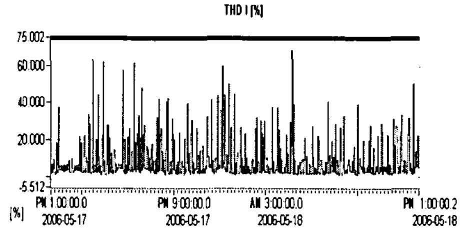

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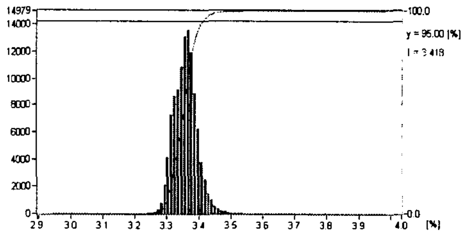
Fig. 4. Measured current magnitude and THD time trends of phase A(without SVC)



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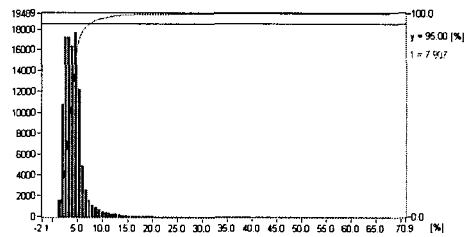

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Fig. 5. Measured voltage and current THD cumulative probability distribution(without SVC)

As illustrated in Figure 3 and Figure 4, the harmonics distortion of the voltage and the harmonics distortion of the current varied with time. To assess the harmonics variation with time, cumulative probability was used. The value corresponding to 98[%] of the CP has been reported as the representative value during the period of measurement[7, 8]

2.4 Harmonics measurement after SVC is thrown in

Table 2 shows the data measured by the PNA-200 instrument after the SVC was thrown in for 24 hours.

Figure 6 illustrates the magnitude of the voltage and harmonics distortion measured for 24 hours using the PNA-2010. Only A phase is displayed for convenience.

Figure 6 shows the magnitude of the current and the harmonics distortion measured for 24 hours using the PNA-2010. Only A phase is displayed for convenience.

Figure 8 shows the cumulative probability distribution measured for 24 hours by the PNA-2010. Only A phase is displayed for convenience.

Table 2. Measured data with SVC

	A phase (mean)	B phase (mean)	C phase (mean)
Voltage[kV]	158.8	159.2	158.7
Current[kA]	0.41	0.42	0.44
Harmonics distortion of voltage[%]	0.445	0.407	0.464
Harmonics distortion of current[%]	3.215	2.996	3.102
validity power[GW]	0.038	0.042	0.038
Outward power [GVA]	0.039	0.044	0.039

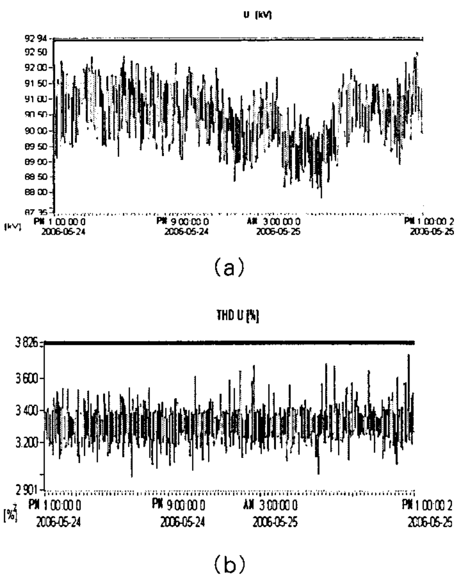


Fig. 6. Measured voltage magnitude and THD time trends(with SVC)

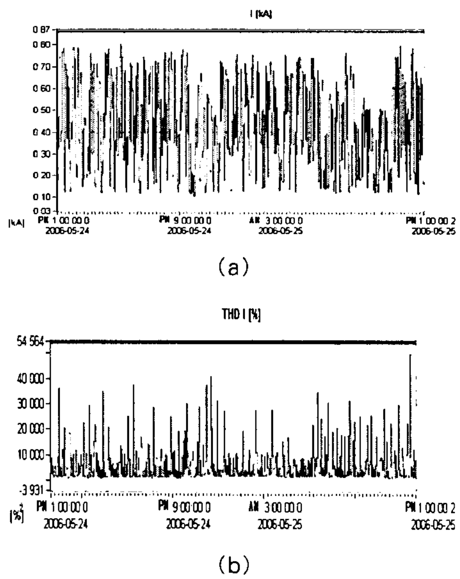
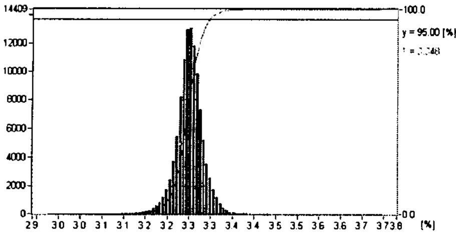


Fig. 7. Measured current magnitude and THD time trends(with SVC)



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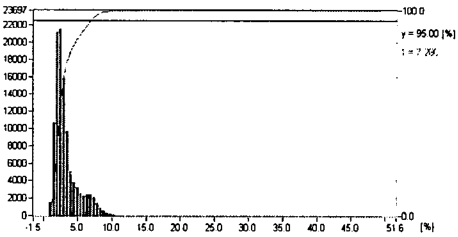

(b)

Fig. 8. Measured voltage and current THD cumulative probability distribution(with SVC)

3.Assessment of the harmonics

Harmonics assessment is based on sharing the role and responsibility between electric power company and customers. The assessment of harmonics voltage is described in the document IEC 61000-3-6[9]. The planning levels is chosen by the electric power company, and it is used for determining the limitation of harmonics emission.

Table 3 summarized the assessment of harmonics voltage. The harmonics distortion of the voltage is the averaged value of A,B,C phase.

The assessment of the harmonics voltage by IEC showed that it was 1.513[%] (less than the standard value of 3.0[%]) before the SVC was throw in, and 1.435[%] afterward. The throw in of the SVC is advantageous compared because its harmonics distortion of the voltage is about 5.16[%] but before the throw in of the SVC, the harmonics distortion exceeds the standard value.

The assessment of the harmonics current by IEC can be briefly distinct to the emission quantity at the first step of the planning level. Table 4 summarizes the assessments of harmonics current. The harmonic distortion of the current is an averaged value taking account Phase A, B, C.

Table 3. Harmonic voltage evaluation by IEC

Numeral of difference	IEC Planning levels	Without SVC	With SVC
2	1.5	0.459	0.647
3	2.0	0.369	0.380
4	1.0	0.788	0.768
5	2.0	0.796	0.491
6	0.5	0.318	0.318
7	2.0	0.313	0.267
8	0.4	0.211	0.154
9	1.0	0.219	0.224
10	0.4	0.131	0.117
11	1.5	0.363	0.372
12	0.2	0.056	0.095
13	1.5	0.161	0.155
14	0.2	0.098	0.092
15	0.3	0.101	0.101
16	0.2	0.095	0.096
17	1.0	0.113	0.111
18	0.2	0.064	0.058
19	1.0	0.051	0.084
20	0.2	0.070	0.064
21	0.2	0.075	0.074
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50	0.2	0.070	0.066
THDv[%]	3.0	1.513	1.435

Table 4. Harmonic current evaluation by IEC

Numeral of difference	IEC limits I_{hi}/I_n([%])	Without SVC	With SVC
5	5~6	1.820	2.183
7	3~4	1.618	1.990
11	1.5~3	1.657	1.375
13	1~2.5	1.616	0.823
$\sqrt{\sum I_h^2}$	6~8	11.721	8.159

주) I_n=rate current(A), I_{hi}= $i$order harmonic current(A)=current rate harmonic current of numeral of difference

The 11.72[%] harmonic current by IEC before throw in exceeded the standard value (6~8[%]). However, after throw in, it became (8.15[%]) close to the standard. The installation of the SVC is shown to have contributed to about 30[%] of the mitigation.

The assessment of the harmonic voltage according to the IEEE Std 519[10] has less the harmonic distortion of the voltage than the standard value (2.5[%]) (1.513[%] before throw in SVC, and 1.435[%] after throw in. The assessment of the harmonic current by IEEE Std 519 was applied, but before the SCR (Short Circuit ratio) should be calculated.

Current of short circuit

$$I_{SC} = \frac{5954MVA}{\sqrt{3} \times 154kVA} = 22322[A]$$

Current of load rate

$$I_L = \frac{285MVA}{\sqrt{3} \times 154kVA} = 1068[A]$$

The ratio of short circuit

$$SCR = \frac{I_{SC}}{I_L} = 20.9$$

The total TDD (Total Demand Distortion) was assessed according to IEEE Std 519.

Table 5 summarizes the assessment of the harmonics. The TDD of the current is an averaged value of phase A, B, C.

The harmonic current assessed by IEEE exceed the standard value (40[%]). It was 11.721[%] before the SVC was thrown in and 8.159 [%] afterward.

Particularly, the harmonic current contains much composition of even difference so that it must be referred of this matter when applying into a filter.

Table 5. Harmonic current evaluation by IEEE

Numeralof difference	IEEE 519 limits	Without SVC	With SVC
3	3.5	2.812	2.764
5	3.5	1.820	2.183
7	3.5	1.618	1.990
9	3.5	1.473	0.760
11	1.75	1.654	1.375
13	1.75	1.616	0.825
15	1.75	1.797	0.682
17	1.25	1.666	0.679
19	1.25	1.547	0.723
21	1.25	1.502	0.696
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49	0.25	2.041	0.916
TDDi[%]	4.0	11.721	8.159
TDDeven[%]	1.0	8.387	5.977

4.Conclusion

It is easy to make a mistake when measuring instantaneous values because the current variation in the load of the electric furnace rise rapidly. For that reason, a safe representative value which is 95[%] of cumulative probability and varies with time is used. The SVC has been installed not only to mitigate the harmonics but also the variation of voltage by compensating the reactive electric power into the load of the electric furnace faster and accurately. The improved effect was analyzed by measuring the harmonic before and after the SVC was thrown in.

The harmonic measurement was carried out according to the international standard IEC 61000-4-7 by the instrument developed.

The assessment of harmonic voltage by IEC 61000-3-6 was less than the standard value 3.0[%] (1.513[%] before SVC was thrown in and 1.435[%] afterward). Due to the effect of the SVC, the harmonic distortion voltage was mitigated for about 5.16[%]. As reference, the standard value of KEPCO (Korea Electricity Power Cooperation) was 1.5[%].

The assessment of the harmonic voltage by IEEE Std 519 exceeded the standard value 4.0[%] (11.721[%] before SVC was thrown in and 8.156 [%] afterward). Due to the effect of the SVC, the harmonic distortion of the current was mitigated for about 30.4[%]. We considered that the customer subjected to the instance study should enforce with respect to the even difference of harmonics and harmonic filter beyond the 11th processing

Acknowledgement

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Biography

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He graduated from electrical engineering department, Hongik University in 1997. He received his M.S. and Ph. D. in electrical engineering from New Mexico State University and the University of Texas at Arlington in 1984 and 1988, respectively. He has been a professor in the Department of Electrical Engineering at Hong-ik University since 1991. His present interests cover the harmonics and grounding analysis of power systems.

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