Investigation of Electrical Load Disturbances Influences on Steel Factory Production Lines

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Abstract: Steel factory is one of the largest consumers from electrical utilities. Performance characteristics of factory loading are crucial to such facility to ensure continuity of the production under higher reliability level of network. This paper illustrates and analyzes different types of disturbances occurred in the steel factory processes plant due to different loads and how that affect factory production. The losses in production lines additional to the cost of disturbance occurring in the system are calculated for one year under the best estimate condition. Recommendations of practical solutions to eliminate or minimize the total disturbances due to different factors are presented. Furthermore, all data involved were obtained from real steel factory plant and its rolling mills plant as case study.

Keywords: Arc furnace; Loads; Power quality; Reliability; Steel factory; Static VAR compensator; Rolling mills

1. Introduction

Electrical power disturbances occurring on the steel factory has an impact on all plants including the rolling mill plant, which is more critical, since it has a direct effect on steel production to keep utility profitability as high as possible. The Cause of Such disturbances are faults due steel factory loading, switching in plant processing and on transmission lines. The use of electric arc furnaces (EAF) for steelmaking has grown radically in the last decade. Of the steel made today 36% is produced using electric arc furnace route and this share will reach to 50% by 2030 [1-3].

In reference [4] a dynamic model of electric arc furnace (EAF), suitable for estimation of voltage flicker in power transmission network at the point of common coupling (PCC) is presented. The study found that Flicker values were higher in case of transmission network with lower short circuit power. To solve the voltage fluctuation problem for the industrial customers with EAF, the

Static VAR Compensators (SVC) have been installed by most of the steel plants to obtain the dynamic reactive power compensation for the system. Most of the voltage fluctuation problem of a large steel plant and mitigation strategy was solved by applying the SVC and co-generation, using such approach the voltage fluctuation is reduced by 0.8% to 0.21% using SVC and 0.8% to 0.10% using co-generation [5]. In this study, these mentioned causes of disturbances will be analysed to find optimum possible solutions followed by conclusions and recommendations to demonstrate the effect of SVC. Gerdau Amari steel Manitoba (GAM) located in Selkirk Manitoba Canada operates two electric arc furnaces is introduced [6]. In 2007, a SVC, replacing an old synchronous condenser, was commissioned adjacent to the melt shop for reduction of network disturbances and for power factor correction, it can be seen that the power into the furnace increased from approximately 35 MW (SVC “off”) to approximately 45 MW (SVC “on”) at the same furnace operating taps. By integrating the input power over time to determine input energy for this example, 20 MWh of input energy was supplied in 45 minutes without the SVC, but in only 40 minutes with the SVC in operation. From this example, one can conclude that more steel is melted during a certain time span because of the impact of the SVC, or, vice versa, the same amount of steel can be melted in a shorter time [7].

This paper is structured in a chronological order, starting with a background of the steel company and modes of electric arc furnace as given in Section 2. Providing the power quality issues in steel production utilities in section 3, and associated rolling mill power interruption and corresponding delays. Summary of lost tonnages and relevant cost are given in section 4 (effects of power quality), and eventually conclusions and recommendations to the industry are provide in section 5.

2. Steel plant- Electrical Arc Furnaces (EAF)

The electric arc furnace operates as a batch melting process producing batches of molten steel known "heats". The electric arc furnace operating cycle is called the tap-to-tap cycle chart as shown in Figure.1. It comprises the following operations: Furnace charging, melting, refining, de-slagging, tapping, and furnace turn-around. Recent operations aim for a tap-to-tap time of less than 60 minutes. Some furnace operations of type twin shell are achieving tap-to-tap times of 35 to 40 minutes.

The main function of the EAF is to convert raw material via vessels that turn solid "raw" materials into liquid steel. Table.1 shows the technical specifications of the furnace and Table.2, illustrate its operation parameters.

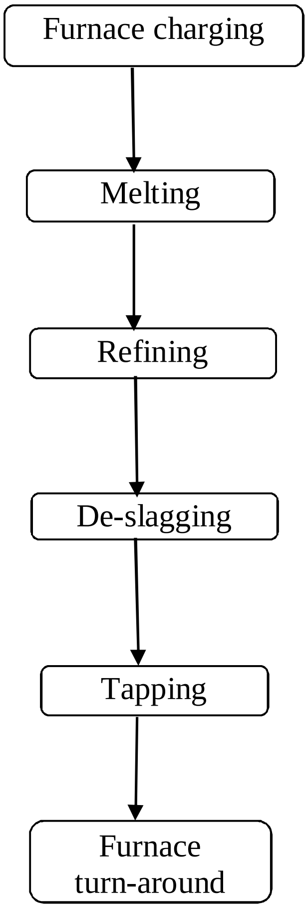


Figure.1 EAF –tap-to-tap cycle chart

Table 1. EAF technical data

Main Operating Parameters	Long Products	Flat Products
Avg. Power on Time	59	53
Avg. Net Tap-to-Tap Time	75	70
Energy Consumption per ton	557	560
Spec. Electrode	1.3 kg/t	1.3 kg/t
Charge Mix (Scrap / DRI)	25% Scrap 75% DRI	25% Scrap 75% DRI
Avg. Tapping Temp.	1620 °C	1620 °C

Table 2. EAF operating parameters

Technical Data	Long Product	Flat Product
Units	3	1
Tapping weight	155	155
Total Charge Capacity	185	185
Shell diameter	6.8 m	7.0 m
Tapping System	EBT	EBT
Electrode Diameter	610 mm	610 mm
Transformer Capacity	110 MVA	120 MVA

Steel factory utilities usually have an input capacity (charging) of 185 ton of raw materials while the output capacity (tapping) is approximately 155 tones. In addition, the difference in the input and output is due slag being produced from non-metallic and losses to the extraction system. A refractory lining is placed into te furnace shell which has a diameter of 6.8 -7.0 m to contain the liquid steel as water cooled panels are used in areas that are not in contact with liquid steel. Particularly, Electricity is the main energy supply in which passes down three carbon electrodes 0.6 meters in diameter to form electric arcs where heat from arcs melts down raw materials. In fact, Oxygen also supplies some energy through chemical reactions within and above the steel. However, melting temperature of steel is estimated as 1500°C where its temperature before tapping varies in a range of 1590°C to 1700°C.

A typical heat balance diagram of the EAF is as shown in Figure.2. Total energy shared by 70% electrical energy and 30% chemical energy. These energies are shared by following proportions 53% steel making process, 10% for slag operation and remaining 37% is unusual energies, 20% waste gas and 17% cooling losses.

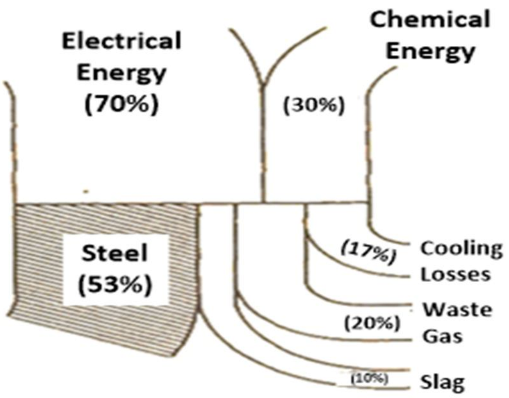
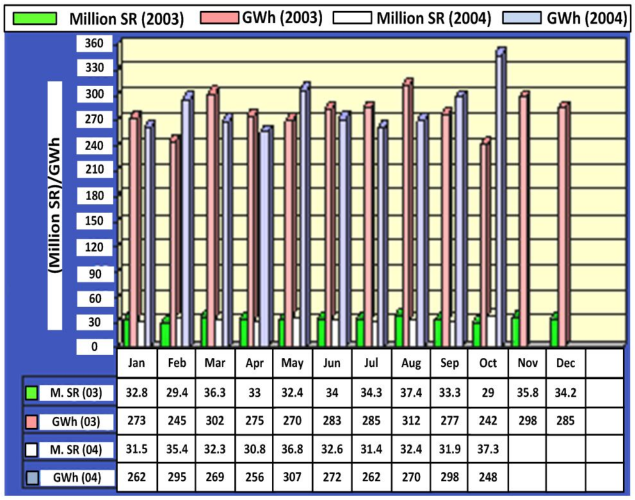


Figure.2 Heat balance diagram of EAF [6]

A. Steel factory power

As an estimated study, steel factory consumes 540-570 MW fed from 230kV two (2) incoming lines from electricity utility side with a thermal capacity of 741 MVA each. In addition, two 34.5 kV incomers feed rolling mills long product via underground cables. Figure.3 below shows the distribution of the power network of the factory plant and power consumption. The results in Figure.3 clearly show each month of year 2003 and 2004 is balanced each other and maintain the stable economic of plant.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
🟩 M. SR (03)	32.8	29.4	36.3	33	32.4	34	34.3	37.4	33.3	29	35.8	34.2	
🟥 GWh (03)	273	245	302	275	270	283	285	312	277	242	298	285	
☐ M. SR (04)	31.5	35.4	32.3	30.8	36.8	32.6	31.4	32.4	31.9	37.3			
▨ GWh (04)	262	295	269	256	307	272	262	270	298	248			

Figure.3 Steel Factory Total Power Consumption (kWh and SR) 2003-04

3. Power quality issues in steel production utilities

The main aim for industrial utilities, steel utilities in this case, is to reach optimum performance of production while maintaining the production cost as economical as possible (cost-efficient production). Essentially, electrical power supply is one of the most economical-efficient ways to reduce cost while optimum production is achieved. Such ways include investment in power quality equipment's specifically such as SVC as it contributes to energy savings leading to lower operation cost.

In the opinion of some people, an SVC is unavoidable that should be avoided whenever possible. Some "strategies" on how to "negotiate away" the SVC construction has been presented in papers [11] in details. Through a few simple examples we shall try to prove the opposite, namely that the improvement of power quality in the supply system, and in particular the installation of a properly designed SVC, is an advantageous investment for steel manufacturers and may bring substantial gains from the production point of view.

We also wish to stress how important it is when designing steel plant power supply that the installation of an SVC should not be considered at the final stage when all other equipment has already been sized and ordered but instead should be a part of an optimization plan for a complete power supply system for a steel plant. This is valid both for brand-new green-field plants and for revamping and extensions of existing plants [11].

Nevertheless, most of loads at steel utilities are inductive in nature in which they directly related to issues of plant reactive power consumption. This controllability of reactive power is important to keep it at optimum level in order to improve network power quality and performance characteristics. Figure.4 below shows typical features of poor voltage quality.

The interconnection point in the grid between the power utility and the steel plant, generally designated PCC, and then becomes a terminal of high importance. This is particularly true now that several countries have begun to deregulate their power transmission systems. Concepts such as "power quality" issues due to EAF were introduced in order to set rules and regulations for networks with an increasing amount of voltage distortions. For an inductive feeding network, which is the most common, it is mathematically simple to show that, setting the plant reactive power at a low value with small fluctuation in time, the network voltage quality will increase considerably even if the fluctuation in active power still exist. [11]

The specific short time under-voltage and over-voltage variations (voltage sags and swells) have a huge impact on sensitive equipment's connected to the network such as protection devices and computers. Such load variations also create network disturbances as unbalanced phases and voltage flickers [9]. The heavy voltage fluctuations caused by the furnace low frequency load current content has a huge impact on reactive power levels. The state-of-the-art SVC enables control to keep the plant reactive power consumption within acceptable limits. The typical SVC comprises of a set of fixed power factor correction Capacitors (FCs) forming harmonic filters to absorb certain harmonics.

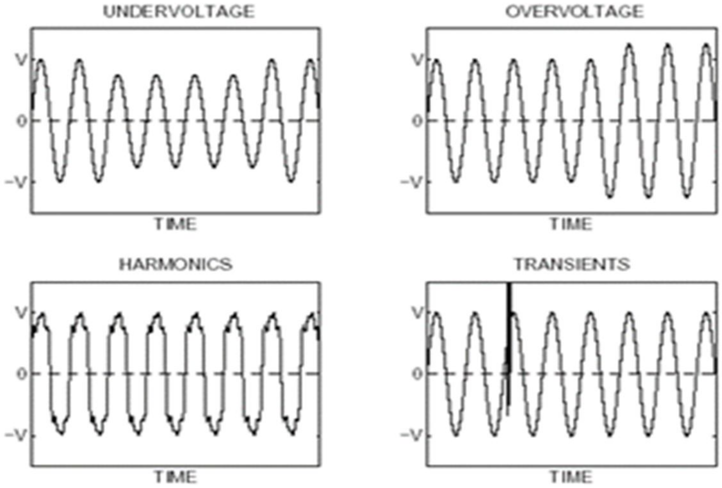


Figure.4 Power quality voltage related issues [7]

Also, the presence of Thermistor Controlled Reactor (TCR) with a fast acting regulator ensures the SVC’s capability to compensate the swing due to plant loading as shown in Figure.5 and Figure.6 illustrate SVC layout.

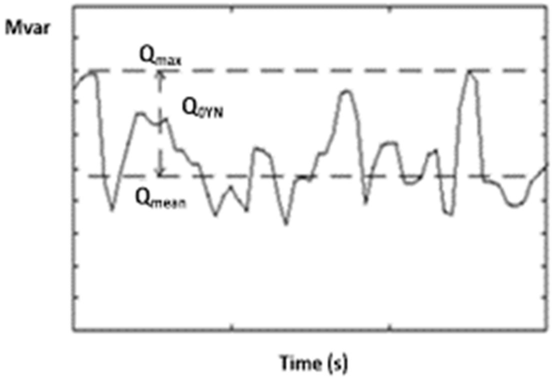


Figure.5 Typical EAF reactive power swing

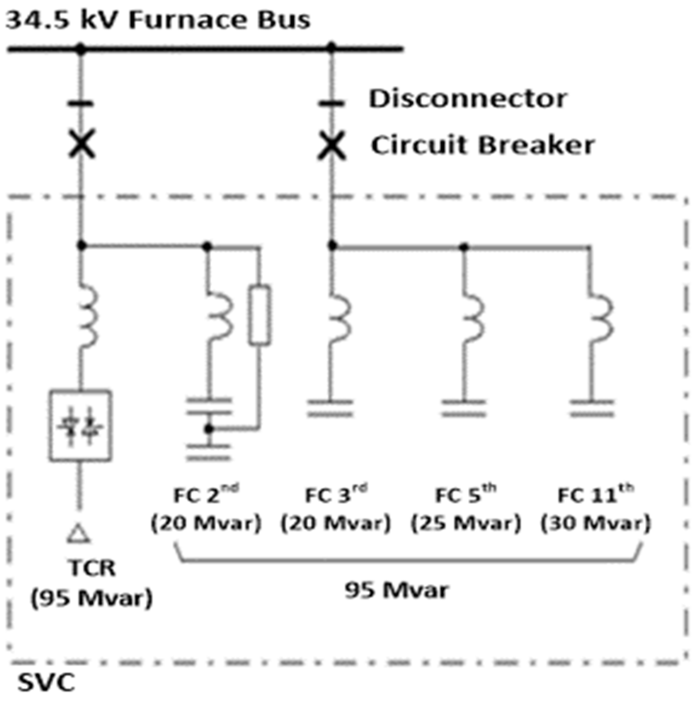


Figure.6 Typical SVC layout in a steel utility plant

A. Voltage fluctuating

A properly designed SVC will largely, attenuate the low frequency flicker down to a more acceptable level, as per the example in [10]. Figure.7 below shows that the SVC is not needed as no signals are above the borderline; however, it is important to understand that it is the total integrated amount of the modulated low frequency signals into the carrier fundamental (50 or 60 Hz) which will create the flicker perception. In practice, it is very seldom that the flicker sensation is generated by only one single frequency and to achieve a necessary margin an SVC will also be needed in such a case as in Figure.4.

B. Power quality aspects and steel plant performance

This section is to show the positive influence and beneficial plant production that operator will obtain by increasing power quality. This demand may seem to be easy to fulfil, but there are complications in compensation of fluctuating loads, which means that careful. The first important parameter is if overcompensation into the utility network is accepted or not. According to our experience of dealing with several heavy steel mills, such a situation will seldom be accepted as a normal condition. Power factor compensation demand with mechanically (CBs, etc.) switched capacitor banks will force frequent switching operations, with both heavy wear and network disturbance as a result [11].

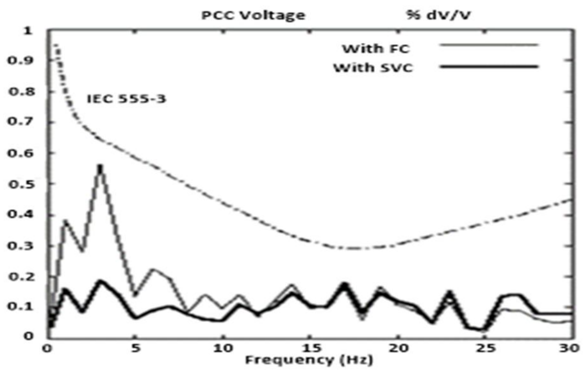


Figure.7 IEC 555-3 gives the maximum permissible percentage voltage changes according

The active power increase will be in the range of 15 % if an SVC is used. The voltage decrease from no-load to the rated arc current is approximately 5-6 % which is less than that without the application of SVC as illustrated in Figure.8. To correct the furnace bus voltage quality by insertion of a tremendously oversized step down transformer may help the furnace operation but will in turn may create unacceptably high flicker at PCC and thus this is not a practical solution.

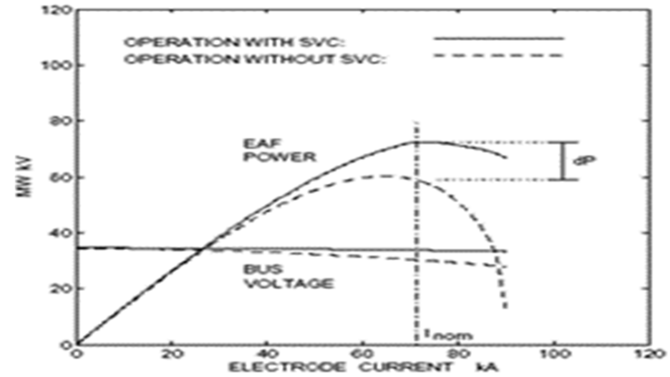


Figure.8 Comparison of bus voltage and power with and without SVC

4. Unscheduled power interruptions

A. Interruptions due to Steel factory loads

Table.7 illustrated as shown in Appendix-A is the unscheduled power interruption due to loads interruptions. Table.4 illustrated shows the unscheduled power interruption due to utility electrical company. Also the number of interruptions for all Steel factory plants in monthly wise for the last five years 2000, 2001, 2002, 2003, and 2004.Table 5 illustrate the lost MW per month based on number of interruptions shown in Table 4.

Table 4. Number of interruptions in all plants due to utility company

	No of interruptions /year wise				
Month	2000	2001	2002	2003	2004
January	4	7	3	4	1
February	4	2	7	1	0
March	3	5	3	3	1
April	2	2	2	0	1
May	9	1	4	0	3
June	2	3	4	2	0
July	2	5	3	2	2
August	2	1	4	1	0
September	2	2	1	0	2
October	5	1	5	5	2
November	1	1	2	6	1
December	0	4	3	2	0
Total	36	34	41	26	13

Table 5. MW lost based on total interruptions per month

Month	Total lost power in MW				
	2000	2001	2002	2003	2004
January	570	560	340	140	10
February	660	220	1100	110	0
March	660	580	230	800	55
April	0	220	760	0	589
May	860	220	777	0	305
June	230	130	725	340	0
July	40	570	45	470	289
August	385	220	725	50	0
September	330	10	220	0	20
October	1050	120	400	710	660
November	220	450	818	669	20
December	0	450	900	330	0

The year 2002 was the worst with 41 interruptions, 7040 MW power lost in plant. Major co-generation was added to avoid interruptions form utility and enhanced coordination and protection with utility was conducted to reduce such interruption.

5. Rolling mill (Case Study)

This plant is taken as a pilot plant for case study. It is the last point in the integrated process and this is where it obtains its importance. Supply to this plant is through two 34.5 kV lines, underground cables as shown in Figure.9.

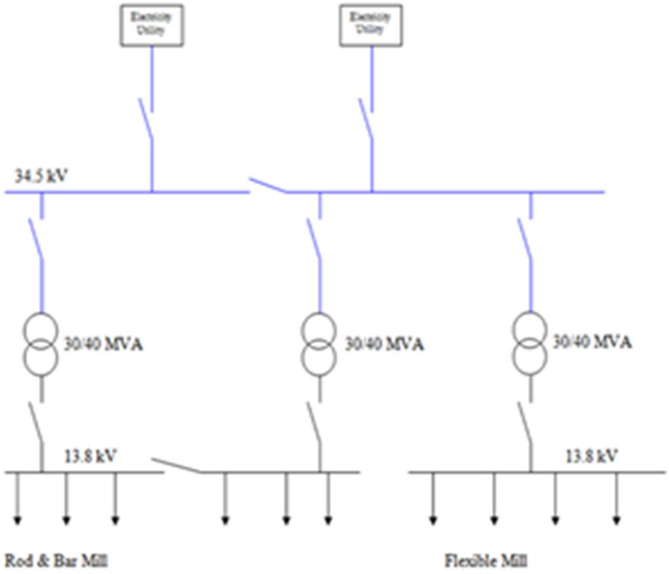
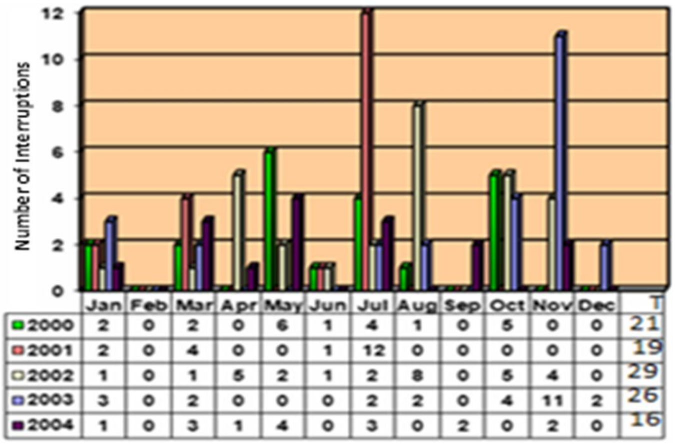


Figure.9 One-line diagram for rolling mill plant supply from 34.5 kV

Figure.10 shows the rolling mill number of power interruptions each month from 2000 to 2004. Again, in the year 2002, more power interruptions incident occur in the plant. After that year, 2003 and 2004 reduced the interruptions by proper operation mitigation methods.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	T
🟩 2000	2	0	2	0	6	1	4	1	0	5	0	0	21
🟥 2001	2	0	4	0	0	1	12	0	0	0	0	0	19
⬜ 2002	1	0	1	5	2	1	2	8	0	5	4	0	29
🟦 2003	3	0	2	0	0	0	2	2	0	4	11	2	26
🟪 2004	1	0	3	1	4	0	3	0	2	0	2	0	16

Figure.10 Rolling mill number of power interruptions per month 2000-04

Table.6 illustrate the delays, lost tonnages and corresponding cost of each month. In specific there is no delay (min) in the months of Feb, Aug, and Dec there was no tonnages cost lost.

Table.6 Delays, lost tonnages, and cost for RMLP

	Delay (min)	Tonnages lost	Cost (SR)
Nov. 03	1532	3037	1,870,578
Dec. 03	141	280	177,064
Jan. 04	7	9	5,462
Feb. 04	0	0	0
March 04	183	292	286,984
April 04	39	96	120,039
May 04	126	217	264,373
June 04	0	0	0
July 04	261	509	631,337
Aug. 04	0	0	0
Sep. 04	188	296	353,250
Oct. 04	0	0	0
Nov. 04	115	163	116,940
Dec. 04	0	0	0
Total	2,592	4,899	3,826,027

6. Conclusion

From the above data, the number of interruptions on the rolling mill plants from year 2001 till 2004 in terms of interruption per year was found as 21, 19, 29, 26, and 16 per year respectively. Additionally, interruptions for the period from November 2003 till December 2004 affected Steel factory from three different aspects, with five months zero interruptions were found as 2,592 delays in minutes, 4,899 tonnes losses in production, and holding a cost of SR 3,826,027 (1$=3.75 SAR). It is noticed that all types of causes such as voltage dip, power outage, line tripping, circuit breaker tripping, load shedding, and unit tripping affected the plant performance. The most frequent ones among all of these types are cable faults, unit tripping, and under frequency load shedding. In fact, feeding such plant using long underground cables are not practical due to the nature of the load and process. The year 2002 was the worst with 41 interruptions, 7040 MW power lost in plant. Major co-generation introduced to avoid interruptions form utility and enhanced coordination and protection with utility this is to reduce such interruption. Therefore, higher voltage level can be applied to the plant for more voltage stability meaning that lesser voltage fluctuating.

References

[1] P. Doulai, “The impact of electric arc furnace operation on power quality of electric supply”, In Proceedings of the International Power Engineering Conference (IPEC99), Singapore, May 1999.pp 751756.

[2] M. H. Shwehdi, “Harmonics investigation in a steel factory. 20th International Conference on Electricity Distribution Prague, 8-11 June 2009.

[3] M. H. Shwehdi, A.H. Mantawy, J. M. Bakhashwain, and Y. El Hawi, “Harmonic Flow Study And Evaluation Of A Petrochemical Plant In Saudi Arabia”, Power Engineering 2002 Large Engineering Systems Conference on, LESCOPE 02, 2002, pp. 165 -172.

[4] Ana Tomasovi´c Tekli´ca, Boˇzidar Filipovi´c-Grˇci´c, Ivica Pavi´c, “Modelling of three-phase electric arc furnace for estimation of voltage flicker in power transmission network”, Electric Power Systems Research 146 (2017) 218–227.

[5] C. S. Chen, H. J. Chuang, C. T. Hsu and S. M. Tseng, “Mitigation of voltage fluctuation for an industrial customer with arc furnace”, 2001 Power Engineering Society Summer Meeting. Conference Proceedings (Cat. No.01CH37262), Vancouver, BC, Canada, 2001, pp. 1610-1615 vol.3.

[6] R. Grünbaum, T. Gustafson, J.-P. Hasler, A. Press, “Improved SVC Performance for Flicker Mitigation of an Electric Arc Furnace”, PR-356-068 - 2009 AISTech Conference Proceedings.

[7] SVC for flicker mitigation from a steel plan. www.abb.com. Accessed on January 8th,2018.

[8] Joseph Seymour, “The seven types of power problems”, white paper-18, are now part of the Schneider Electric white paper library produced by Schneider Electric’s Data Centre Science Centre DCSC@Schneider-Electric.com

[9] Haixue.L, “Introduction of the new national standard of Power quality voltage fluctuation and flicker”, Forum Electricity 18(6), 4–7 (2001)

[10] Zhengyuan ZHAO , Feng XU ,Ke LI, “Voltage flicker reduction with SVC in steel plant”, 23rd International Conference on Electricity Distribution Lyon, 15-18 June 2015.

[11] Antonio Silva, “Steel plant performance. power supply system design and power quality aspects”, 54th Electric furnace conference, Dec’96.

Appendix-A

Table 7. Delays due to Steel factory loads for two years

Year	Month	Compensation				Power Station				Flow Power				
		EAF 1	EAF 2	EAF 3	EAF 4	EAF 1	EAF 2	EAF 3	EAF 4	EAF 1	EAF 2	EAF 3	EAF 4	Total
2003	January	0	0	0		18	204	17		12	13	0		264
	February	0	0	0		17	284	31		16	23	7		378
	March	0	0	0		13	173	19		4	24	7		240
	April	0	0	0		17	194	47		16	13	30		317
	May	0	0	0		209	206	27		0	21	12		475
	June	0	0	0		35	252	44		22	41	19		413
	July	0	71	0		6	63	6		4	21	7		178
	August	17	139	5		4	25	11		15	42	16		274
	September	19	156	6		0	8	8		3	94	6		300
	October	3	114	11		1	0	0		5	19	6		159
	November	9	150	2		0	0	2		12	75	0		250
	December	2	96	1		90	92	79		0	46	0		406
	Total	50	726	25		410	1501	291		109	432	110		**3654**
2004	January	3	128	1		7	45	2		0	76	0		262
	February	0	113	0		0	10	0		0	72	0		195
	March	6	78	2	9	9	27	0	1045	3	20	0	43	1242
	April	1	93	1	19	0	14	0	18	0	23	0	0	169
	May	1	109	2	23	10	11	4	3	0	24	0	0	187
	June	4	72	0	16	0	2	5	15	9	0	0	0	123
	July	1	70	0	13	84	130	86	0	0	18	0	0	402
	August	2	70	4	4.6	0	6	2	0	6	764	0	0	859
	September	20	119	0	3.3	1	0	0	0	23	13	0	0	179
	October	22	132	25	13	3	24	1	1	26	125	7	0	379
	November	59	83	25	7.1	0	0	0	1	122	80	12	0	389
	December													0
	Total	119	1067	60	108	114	269	100	1083	189	1215	19	43	**4386**