PQ Case Study

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Static VAR Compensator Fails to Mitigate Flicker from Electric Arc **Furnace Operation at a Steel Plant**

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SUMMARY

Flicker from an electric arc furnace at a steel plant was being mitigated by a series reactor that was used to control the melting process and by a static VAR compensator (SVC), but utility customers were still experiencing problems. A measurement- and modeling-based analysis was commissioned to characterize flicker levels, identify the reasons for excessive flicker levels, and propose solutions to limit the flicker to acceptable levels. EPRI performed the recording of real-time data at the site using a multichannel data acquisition system. To assess the effectiveness of the SVC in compensating for the reactive power variations of the furnace, time-domain recording data were also processed to compute reactive power of the furnace, the reactive compensation provided by the SVC system, and the net reactive power seen at the step-down transformer. In this case, results pointed to replacement of the SVC as the best option.

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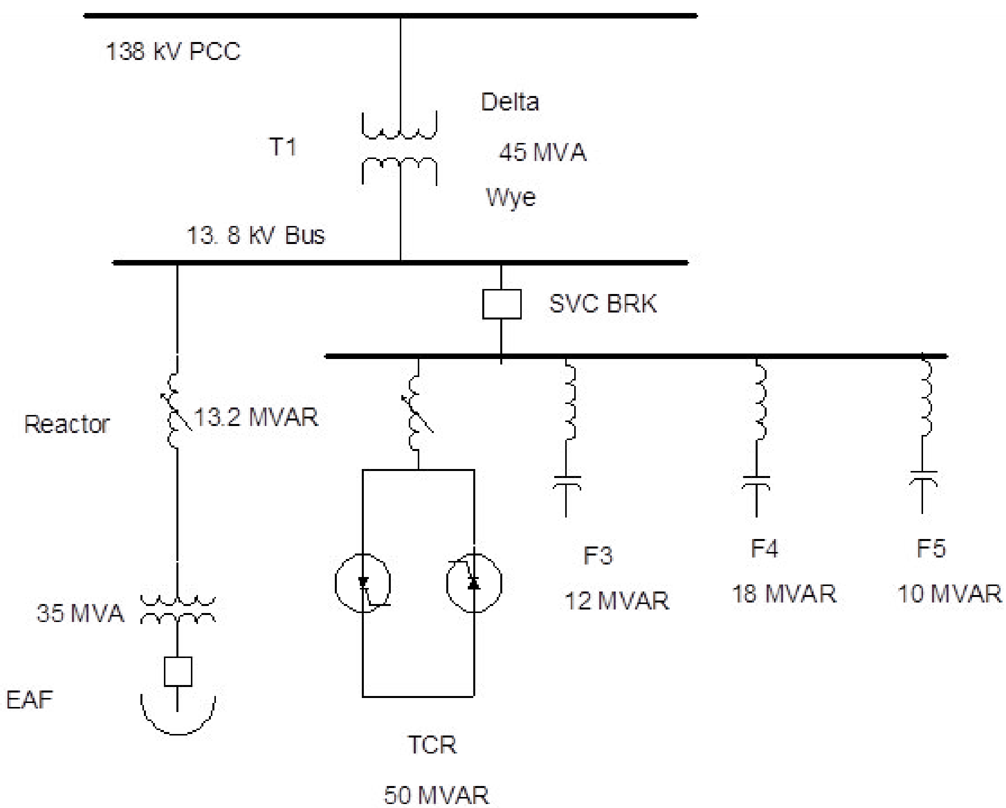
Static VAR Compensator Fails to Mitigate Flicker from Electric Arc Furnace Operation at a Steel Plant

BACKGROUND

The operation of an electric arc furnace (EAF) at a steel plant was causing flicker complaints from utility customers served from the same 138-kV system. The 138-kV bus was considered the point of common coupling (PCC). The simplified single-line diagram of the EAF plant is shown in **Figure 1**.

Figure 1. Electric Arc Furnace Facility Single-Line Diagram



The plant receives power from the utility system via either a 45MVA or a 36MVA, 138/13.8kV substation transformer. The EAF is served from the 13.8-kV secondary bus via a 4.5-mH variable current limiting reactor and a 35MVA, 13.8/0.532kV transformer. The reactor is stepped in as necessary to control the melting process by maintaining a more constant arc. A side benefit of the reactor is that it helps to mitigate flicker. A static VAR compensator (SVC) also supports the substation transformer 13.8-kV secondary bus serving the EAF. The SVC system comprises a thyristor-controlled reactor (TCR) and filter banks for the 3rd, 5th, and 7th harmonics. The configuration of the SVC system is shown in **Table 1**.

Table 1. SVC Components

Component	Mvar	Nature	Tuning Frequency (Hz)
TCR	50.02	Inductive	
3rd harmonic filter	12.21	Capacitive	216.39
5th harmonic filter	18.32	Capacitive	232.59
7th harmonic filter	10.3	Capacitive	293.54

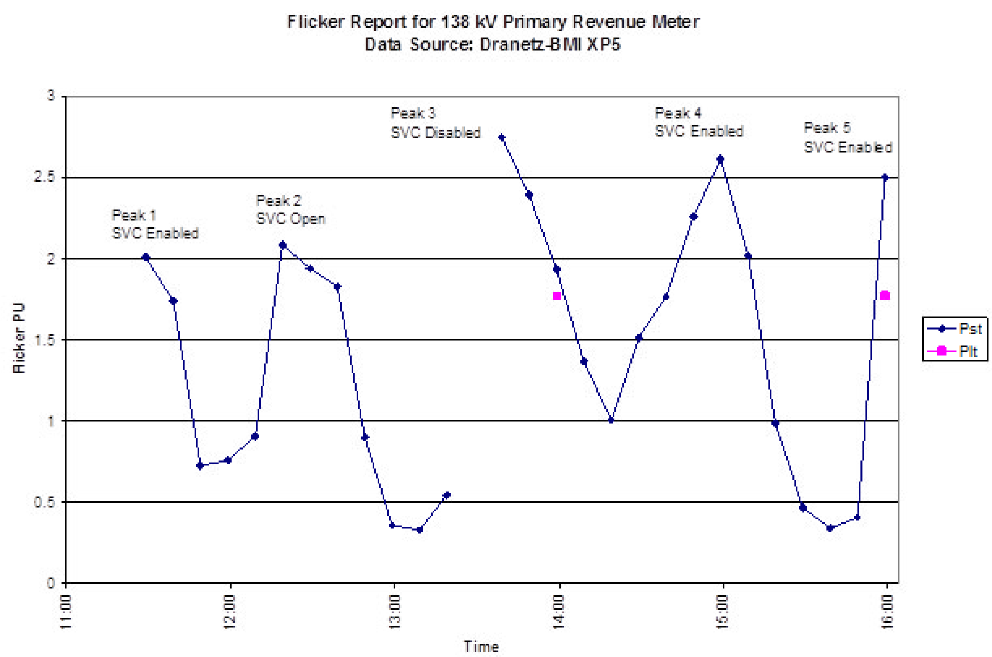
The control system of the SVC contained three different regulators. Reactive compensation was controlled by a three-phase open Q-regulator. The open Q-regulator made use of the reactive power measured in each phase of the EAF at the 13.8-kV bus. The second regulator was a power factor regulator that attempted to keep the power factor on the 138-kV bus as close to unity as possible. The active and reactive power measured at the 13.8-kV bus served as input to this regulator. Finally, there was a voltage regulator that monitored and worked to maintain the voltage on the 13.8-kV bus.

EPRI was contracted to perform a measurement- and modeling-based analysis to characterize flicker levels, identify the reasons for excessive flicker levels, and propose solutions to limit the flicker to acceptable levels.

ON-SITE MONITORING AND MEASUREMENT ANALYSIS

EPRI performed the recording of real-time data at the site using a multichannel data acquisition system. The data were acquired for the voltages at the 138-kV and 13.8-kV busses. Additionally, the currents drawn by the SVC system, the EAF, and the step-down transformer were recorded. The test protocol was devised in a way that covered several scenarios. All the recordings were performed for the duration of 1 minute at a sampling rate of 20,000 samples per second. For the entire monitoring period, flicker values (Pst and Plt) were also measured and are plotted in **Figure 2**.

Figure 2. Flicker Measurement at PCC



The peaks shown in Figure 2 correspond to the first melting stage of the EAF. During this stage, arcing is severe and highly random in nature, resulting in high Pst values.[1] The peaks are followed by the flat bath stage in EAF when the arcing is relatively subdued, resulting in lower Pst values. The system conditions during these peaks are listed in **Table 2**.

Table 2. System Conditions During Monitoring Period

Peak Number	Step-Down Transformer (MVA)	TCR Status	Filter Banks Status
Peak 1	45	ON	ON
Peak 2	45	OFF	OFF
Peak 3	45	OFF	ON
Peak 4	36	ON	ON
Peak 5	45	ON	ON

Peaks 1, 4, and 5 in Figure 2 correspond to the time periods when the SVC system was enabled, meaning that both the TCR and the filter banks were in service. Peak 2 corresponds to the time period when the SVC breaker was open, meaning that both the TCR and the filters were out of service. Peak 3 corresponds to the period when the SVC breaker was closed but SVC was disabled, meaning that TCR was disabled but filters were in service. A few basic observations can be made from the flicker measurements:

1. The SVC was not having a significant effect on the flicker levels. Peak flicker levels during the unstable arc period (first melting stage) were similar with or without the SVC. These were likely the flicker periods that result in customer complaints.

2. The flicker levels were not magnified with only the filters in service. This provided some indication that the suspected magnification of interharmonic components by filters was not contributing significantly to the overall flicker levels.

3. The flicker levels were not significantly dependent on the step-down transformer size.

The time-domain recording data were also processed to compute reactive power of the furnace, the reactive compensation provided by the SVC system, and the net reactive power seen at the 138-kV side of the step-down transformer. The results were used to assess the effectiveness of the SVC in compensating for the reactive power variations of the furnace. These reactive power variations are the main cause of the flicker. The response of the SVC to these reactive power variations was used to evaluate the response time of the SVC, which relates directly to its ability to improve the resulting flicker levels.

Phase A reactive power for the entire measurement period is shown in **Figure 3**. The measurement data show that the SVC is providing sufficient compensation as far as the magnitude is concerned, resulting in an average net reactive power near zero. However, the actual variations in the net reactive power are still substantial, and it is these variations that result in flicker.

To further the analysis, a 1-second period during the initial bore-in period was used for the detailed analysis in order to provide a more detailed assessment of the response time characteristics of the SVC (see **Figure 4**). The measurement data show that the SVC is not able to compensate for the fast variations in the furnace reactive power, and actually introduces some reactive power oscillations.

Looking at the total three-phase reactive power fluctuations is also useful to assess the total reactive compensation requirements (possible need for larger SVC capacity). The combined three-phase reactive power plots for the entire duration are shown in **Figure 5**. It is observed that three-phase reactive power demand at the furnace mostly varies between 20 and 40 MVAR (after the first few seconds). The SVC system (TCR rating) in its existing configuration had the capacity to meet this range of reactive power fluctuations and was in fact operating within its control range for these fluctuations. This would indicate that merely increasing the size of the TCR would not likely provide a significant reduction in flicker.

Figure 3. Single-Phase Reactive Power Variations (1-minute duration)

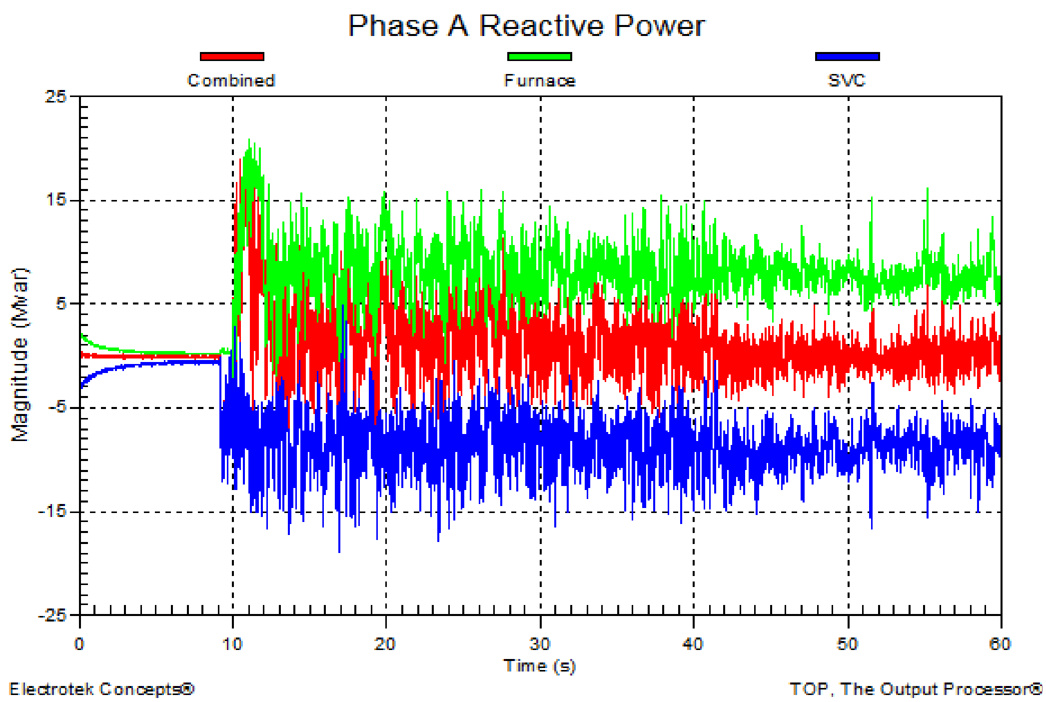


Figure 4. Single-Phase Reactive Power Variations (1-second duration)

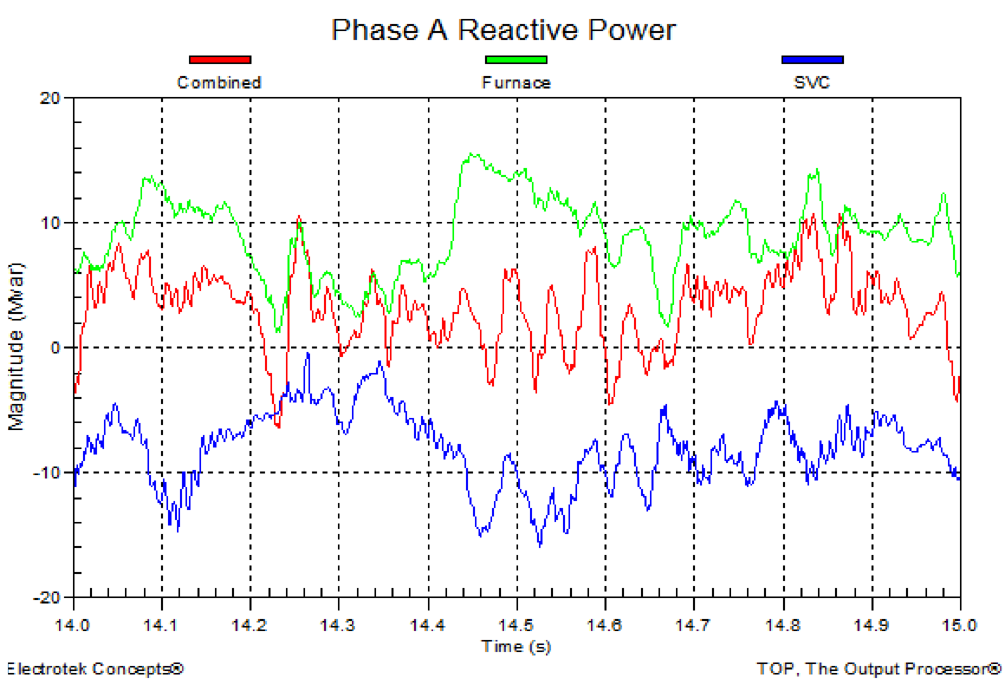
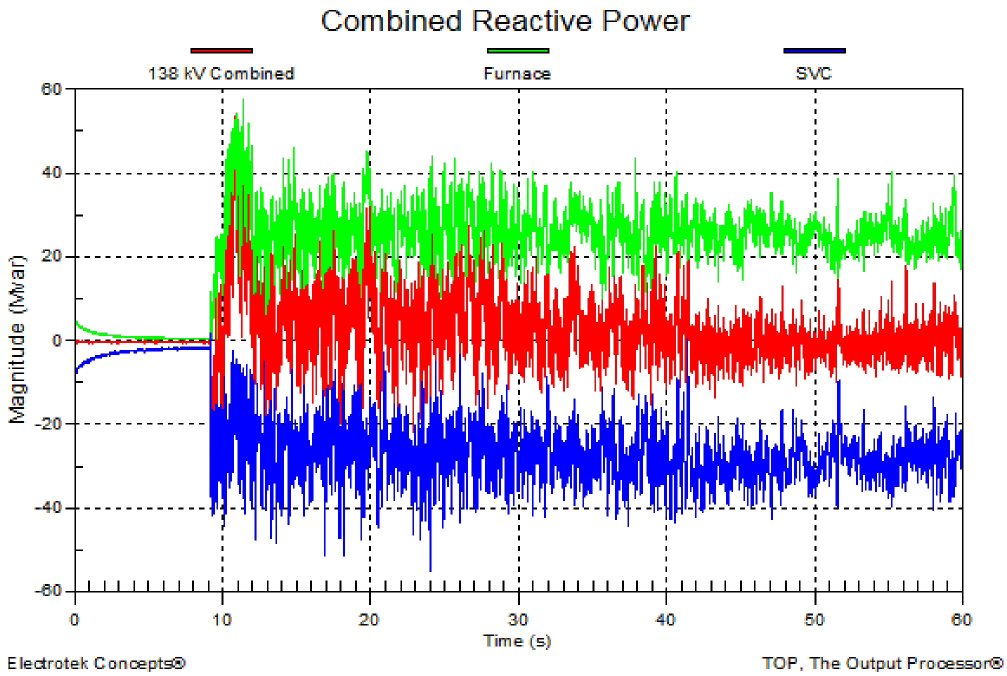


Figure 5. Three-Phase Reactive Power Variations



SUMMARY AND RECOMMENDATIONS

The following observations resulted from the analysis of the measured data:

- Pst flicker levels as high as 2.7 were recorded during the first melting stage of EAF. Pst-95% levels were on the order of 2.0 with or without the SVC operating.
- The SVC system in its existing configuration was not helping to mitigate the flicker arising out of the EAF operation.
- The SVC system seemed to have enough capacity to provide the desired amount of reactive power compensation (able to respond to the reactive power fluctuations of the furnace).
- The SVC response time was not fast enough to provide the desired reactive power compensation.

The following recommendations/options were provided to achieve the desired level of flicker mitigation:

- Replace the control system to achieve a faster response time.
- Replace the entire SVC with new SVC/STATCOM.

The implemented solution in this case has been reported to be a new SVC to replace the old one.

NOTES

1. R. Horton, T. A. Haskew, and R. F. Burch, "A Time-Domain AC Electric Arc Furnace Model for Flicker Planning Studies," *IEEE Transactions on Power Delivery*, Vol. 24, Issue 3, 2009, pp. 1450–1457

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