

SVC Control Upgrade Enhances EAF Operations at Nucor Memphis Inc.

Eric Martinez Mora¹, Elizabeth Hayes², Victor Hinojosa³, Bernardo Sainz Barajas⁴, Jose Luis Pepe⁵, Jorge Fernández⁶

¹AMI Automation
Díaz Ordaz 402, NL, México, 64650
E-mail: eric.martinez@amiautomation.com

²Nucor Steel Memphis, Inc.
3601 Paul R. Lowry Rd, Tennessee, USA, 38109
Email: elizabeth.hayes@nucor.com

³Nucor Steel Memphis, Inc.
3601 Paul R. Lowry Rd, Tennessee, USA, 38109
Email: victor.hinojosa@nucor.com

⁴AMI Automation
Díaz Ordaz 402, NL, México, 64650
E-mail:bernardo.sainz@amiautomation.com

⁵AMI Automation
Díaz Ordaz 402, NL, México, 64650
E-mail: jose.pepe@amiautomation.com

⁶AMI Automation
Díaz Ordaz 402, NL, México, 64650
E-mail: jorge.fernandez@amiautomation.com

ABSTRACT

A Static VAR Compensator (SVC) regulates voltage stability, improves power factor, and compensates for reactive power in electrical systems. Electric Arc Furnaces (EAFs), known for causing voltage fluctuations and harmonic distortion, greatly benefit from SVC integration. To address obsolescence, enhance reliability, and secure better service support, Nucor Memphis upgraded the SVC control system in its Meltshop. This modernization not only met these objectives but also delivered significant operational improvements, including reduced short-circuit and overload events, lower electrode consumption, and increased furnace uptime through minimized downtime. These enhancements were achieved while maintaining voltage stability, flicker mitigation, power factor correction, and existing harmonic distortion levels. By adopting advanced technology, Nucor mitigates risks, ensures continuous service availability, and enables future scalability, including seamless integration with AMI PX3 Electrode Regulation System and Smart Furnace.

Keywords: SVC (Static VAR Compensator), EAF (Electric Arc Furnace), Power Quality, Voltage Stability, Harmonic Distortion, Power Factor Improvement, Flicker, PST (Short-Term Flicker Severity), PLT (Long-Term Flicker Severity), Steel Production Efficiency.

INTRODUCTION

Static VAR Compensators (SVCs) are critical for systems involving power utility grids supplying Electric Arc Furnaces (EAFs). SVCs not only compensate for disturbances generated by the load and mitigate adverse effects on power quality parameters seen by neighboring loads but also ensure the availability and stability of power for the production process of the electric furnace in steel production.

Electric Arc Furnaces are very large loads reaching up to 300 MVA and are highly disruptive with power factors as low as 0.6 and current imbalances up to 70%. Typically, they use a three-phase substation transformer to step down voltage from high to medium levels, followed by a furnace transformer to further reduce the voltage to around 600 to 1200 volts in three phases. A reactor is used to limit current, and the furnace impedance is controlled by adjusting the gap between the electrodes and the scrap or molten steel.

The melting process is highly erratic due to the distribution and form of the scrap material. Electrical current can vary significantly or even create disconnections between the electrodes and the material, causing abrupt variations that lead to current imbalances or heavy transients.

Nucor Memphis's EAF operations faced challenges with their existing SVC control interfaces and propriety printed circuit boards, which were approaching obsolescence. The aging system posed reliability and maintainability concerns, threatening to disrupt production and impact product quality. To address these challenges, Nucor Memphis embarked on a comprehensive upgrade of their SVC control system.

NEED FOR SVC UPGRADE AT NUCOR MEMPHIS

The existing SVC system at Nucor Memphis is a Thyristor Controlled Reactor (TCR) type, designed to handle the reactive power compensation needs of their Electric Arc Furnace (EAF). The EAF at Nucor Memphis is a large AC furnace with a rated power of 120 MVA and a voltage ratio of 34.5 / 1.300 kV. This furnace can reach power levels up to 103 MW, making it a highly disruptive load with power factors as low as 0.6 and current imbalances up to 70%.

The SVC power topology consists of a TCR rated at 155 MVAR, which provides dynamic reactive power compensation, and three harmonic filter branches designed to mitigate voltage harmonic distortion, provide fixed reactive leading power and support system stability:

- 35 MVAR Filter Circuit tuned to 120 Hz (2nd harmonic).
- 60 MVAR Filter Circuit tuned to 180 Hz (3rd harmonic).
- 50 MVAR Filter Circuit tuned to 240 Hz (4th harmonic).

These components are connected in shunt to the 34.5 kV bus, which supplies the EAF circuit, ensuring fast response to voltage fluctuations and flicker mitigation. The system also includes medium voltage circuit breakers for both the TCR and filter banks, allowing for individual operation, protection, and maintenance.

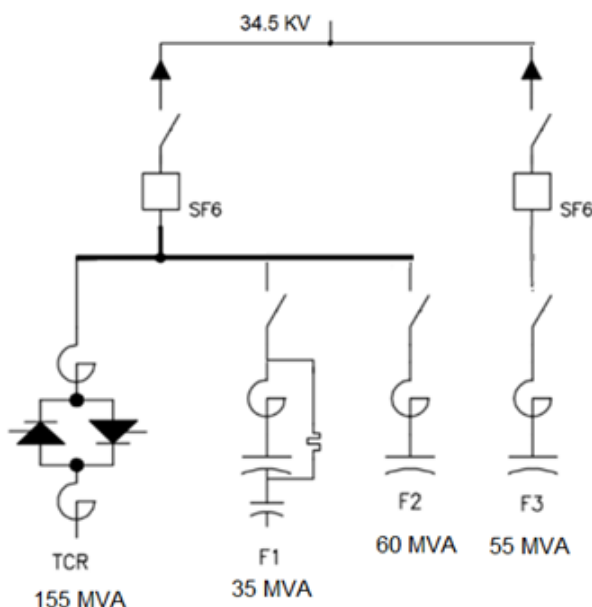


Figure 1. Nucor Memphis SVC Topology.

The plant's electrical system includes a Point of Common Coupling (PCC) with a rated voltage of 500 kV and a short circuit level ranging from 16,000 MVA to 17,000 MVA. The four single-phase step-down transformers at the PCC have a combined rating of 150 MVA with an impedance voltage of 11.4%. The medium voltage system operates at 34.5 kV with a calculated short circuit level of 750 MVA.

The SVC system was originally designed to stabilize the busbar voltage and reduce flicker, with a rating of 145 MVAR. However, due to the aging components, control algorithms not specifically designed for EAF type of loads, and lack of modern diagnostic capabilities, the system experienced some availability problems and struggled to maintain performance during unbalanced operation of the furnace.

The primary issues with the previous SVC system included:

- **Difficulties in Fault Identification:** The old system had limited diagnostic capabilities, making it challenging to identify and troubleshoot faults effectively.
- **Limited Diagnostics and Visibility:** The system provided minimal visibility into operational parameters, making proactive maintenance and real-time monitoring more challenging.
- **Frequent and Hard-to-Repair Failures:** Aging printed circuit boards began failing at an increasing rate and increasingly harder to obtain through the manufacturer. Additionally, intrusive HMI upgrade was being forced due to available spare parts and outdated technology.
- **Need for Better Service Support:** The original manufacturer divested the SVC technology to another company. Eventually, this led to less availability on parts and service providers.

Given these challenges, Nucor Memphis considered a comprehensive upgrade of their SVC control system. The upgrade aimed to address the obsolescence issues by replacing legacy components with modern, supportable equivalents, improving the control system architecture, and enhancing operator interface and monitoring capabilities. This upgrade was essential to ensure long-term reliability, maintainability, and enhanced performance of the SVC system while supporting the stability and efficiency of the EAF operations.

SVC UPGRADE PROCESS

Objectives and Scope of the Upgrade

To address the obsolescence of the existing SVC control system, Nucor Memphis and AMI Automation collaborated on a targeted modernization strategy that would enhance reliability, improve diagnostic capabilities, and ensure long-term maintainability, without requiring a full replacement. The upgrade focused on modernizing the controls, monitoring, and LTT firing circuitry, while preserving existing power infrastructure and cooling unit to minimize downtime and optimize costs.

The scope of the upgrade included:

- Design a new SVC control system architecture to handle the dynamic nature of EAF operations more effectively.
- Replace legacy components with modern, supportable equivalents to ensure long-term system sustainability.
- Enhance operator interface and monitoring capabilities with advanced diagnostic tools and real-time data visualization.

- Retain key power components such as LTT thyristor valve assemblies, TCR reactors, harmonic filters, disconnectors, circuit breakers, and cooling unit ensuring compatibility with the plant's existing infrastructure.
- Update protection relays to enhance fault detection, protection response, and overall system stability.

Through these improvements, the new SVC system integrates cutting-edge control strategies, ensuring optimized power factor and voltage regulation, enhanced reactive power compensation, and increased operational flexibility.

Technology and Implementation Strategy

The SVC control upgrade at Nucor Memphis was built upon AMI's DigiFCR-SVC platform, which integrates advanced regulation, firing control, and system monitoring to enhance overall performance. The key improvements included:

- **AMI's PXC Control Platform:** Enhanced voltage regulation and reactive power compensation, ensuring stable system operation.
- **New Firing Circuitry with Laser Amplifier Boards:** Optimized thyristor triggering precision, improving response time and reliability.
- **LTT Monitoring Cards:** Provided real-time monitoring and diagnostics of thyristor status, improving fault detection and predictive maintenance.
- **Updated I/O System:** Improved signal processing and communication, enabling seamless integration with plant operations.
- **Integration of Cooling System Control:** The existing cooling unit was maintained and incorporated into the new control system.
- **New Protection Relays:** Upgraded fault detection and capacitor bank protection response, reinforcing grid stability and protecting power components.

Nucor Memphis and AMI Automation executed the upgrade through a structured approach, leveraging a digital twin for detailed system characterization and simulation-driven pre-commissioning which accelerated deployment and reduced operational risks.

Optimized Installation and Commissioning

The project team strategically planned installation and commissioning:

- **Project Planning and Coordination:** AMI worked closely with Nucor Memphis to align implementation with production schedules, minimizing disruption.
- **Pre-Commissioning Simulations:**
 - Detailed system studies characterized the electrical network to optimize SVC performance.
 - Simulated commissioning helped pre-tune critical control parameters, reducing on-site adjustments.
 - Fault scenarios were analyzed, improving response to real-world disturbances.

- **Factory Acceptance Testing (FAT):**
 - A low scale model of the SVC system was built to replicate real operating conditions and validate control performance before installation.
 - Extensive functional tests were conducted at AMI's facilities to verify system response and stability.
 - Tests were witnessed by the customer, ensuring compliance with operational requirements before deployment.
- **Component Installation:** The system replacement was executed during a planned outage, ensuring that the new control system fit within the existing layout.
- **Final Testing and Validation:**
 - Comprehensive system tests were performed to confirm operational reliability.
 - Live performance monitoring ensured proper integration with the furnace's electrical system.
 - Fine-tuning adjustments were made based on real-time operating conditions.
 - This structured methodology allowed for a more reliable startup and a faster return to full operation.

Challenges and Execution Approach

The upgrade presented several key challenges:

- **Short Implementation Timeline:** Aggressive six-month timeline required efficient planning.
- **Integration with Existing Infrastructure:** The control system cabinet had to match Nucor Memphis's existing SVC control house footprint.
- **Limited Outage Window:** The upgrade was executed on a tight schedule and successfully started without disrupting production.

AMI and Nucor Memphis efficiently navigated these challenges, delivering a reliable and fully integrated upgraded system, which was successfully commissioned and put into operation on June 14, 2024.

RESULTS

Enhanced monitoring and diagnostic tools

The new state-of-the-art high-performance controller provided enhanced diagnostics tools and ultra-high-speed trends with a sampling rate up to 4 μ s, as shown in **Figure 2**. All these tools available through web browser allowed Nucor Memphis to troubleshoot in a more effective and accurate way. The capability to identify failure root causes faster increased system availability and furnace up time.

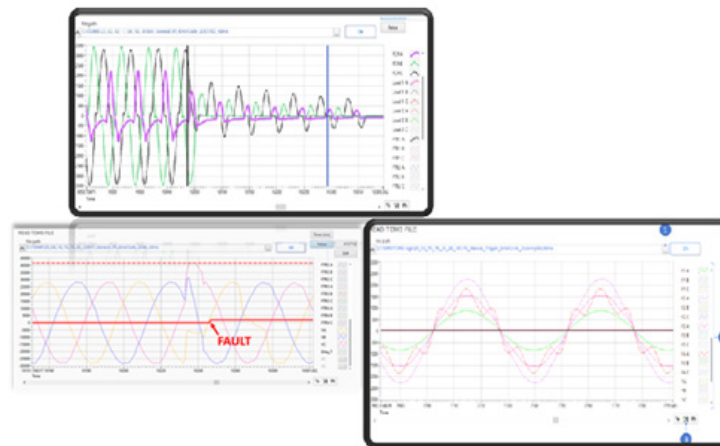


Figure 2. High speed trends with a sampling rate of $4\mu\text{s}$

Power Quality and Electrical Stress

Following the SVC control upgrade, fundamental power quality parameters, such as bus voltage stability, harmonic distortion levels, and flicker indices, generally remain consistent with previous performance, as shown in **Table 1**. In practice, the modernized control algorithms offer improved diagnostic insight and faster fault isolation, resulting in fewer unplanned stoppages despite similar key power quality indicators.

Electrical Parameter (Unit)	Before	After	Limit	Change Observed
Frequency (Hz)	60.02	60.02	-	No change
Rapid Voltage Changes (events/day)	2	2	5	No change
Flicker PST	0.61	0.64	0.8	Slight increase, still within limit
Flicker PLT	0.5	0.5	0.6	No change
Voltage Total Harmonic Distortion (THD) (%)	1.25	1.37	1.5	Slight increase, still within limit
Power Factor (-)	0.999	0.999	-	No change

Table 1. Power Quality Parameters Comparison before and after the upgrade

A more significant improvement emerged in short-circuit and overload counts, which declined after the upgrade. Specifically, short-circuit occurrences were reduced by 18.2%, while overload counts dropped by 3.9%, as found in Table 2. This reduction directly alleviates stress on major components, particularly the EAF power transformer, helping to minimize failures, extend transformer life, and reduce unplanned maintenance interventions. Operators have observed that fewer electrical “shocks” on the meltshop’s infrastructure correlate with less maintenance downtime, ultimately benefiting both reliability and production continuity. Importantly, the advanced SVC logic remains resilient under severe operational conditions, including when the furnace inadvertently transitions to single-phase operation. By adjusting its firing angles and reactive power output rapidly in these scenarios, the new SVC design can sustain a stable arc and avoid full shutdowns.

Production Throughput

Data from the plant’s internal reports reveal modest but meaningful gains in uptime, as proven by fewer fault-related interruptions, also shown in **Table 2**. While “Power On” duration and total energy per heat varied only slightly ($\pm 2\%$), the cumulative effect of minimal electrical disruptions has enabled more consistent furnace operation.

This improvement was achieved through the new control system’s advanced algorithms, which actively correct for unbalanced loads or temporary single-phase operation, ensuring a continuous melting process under conditions that previously led to partial shutdowns or extended downtime.

Potential Impact on Electrode and Refractory Wear

The RWI (Resistance Wear Index) and I^2t (Current Squared Integral over Time) values after the upgrade provide indirect indicators of electrode consumption and refractory wear. In the evaluation period, RWI decreased from 17.71 to 17.38 (-1.87%), while I^2t per MWh increased slightly from 42.76 to 43.12 (+0.84%). These values suggest that while overall energy transfer to the furnace remained stable, arc stability and electrode performance improved, potentially leading to more controlled energy input and reduced wear on both electrodes and refractory linings.

Although there are not direct measurements of electrode consumption and refractory wear, these indicators align with historical data at similar facilities, where a reduction in short-circuit events has been associated with fewer electrode breakages and less uneven refractory degradation. Over a longer period, continued monitoring of graphite usage, refractory wear rates, and maintenance intervals could help validate these potential improvements and quantify their long-term impact on operating costs.

Production Parameter	Before Upgrade	After Upgrade	Relative Change
Delay Events	36	2	Considerable decrease
Average Tons per Heat	Baseline	Slight increase	Marginal improvement
Second Charge Tons per Heat	Baseline	Slight increase	Marginal improvement
Short-Circuit Events	Baseline	-18.20%	Reduction in electrical stress
Overload Events	Baseline	-3.90%	Reduced operational strain
Refractory Wear Index (RWI)	Baseline	-1.87%	Potential improvement
l ² t per MWh	Baseline	0.84%	Slight increase

Table II. Production Parameters Comparison before and after the upgrade

CONCLUSIONS

The SVC control upgrade at Nucor Memphis successfully addressed system obsolescence while maintaining power quality, improving operational stability, and extending equipment lifespan. By modernizing the control platform while preserving existing power infrastructure, the upgrade provided a cost-effective alternative to a full system replacement.

The project delivered key operational benefits, including:

- Increased equipment reliability, with a 18.2% reduction in short-circuit occurrences and a 3.9% drop in overload counts, reducing stress on critical components such as the EAF power transformer.
- More stable arc conditions, reflected in a 1.87% reduction in RWI, which may contribute to improved refractory lifespan.
- 18.9% increase in the number of heats processed, leading to greater furnace availability and higher total steel production.

The success of this upgrade was accomplished by AMI's DigiFCR-SVC platform, which integrates advanced regulation, realtime monitoring, and optimized firing control. Additionally, the use of pre-commissioning simulations, scaled model FAT testing, and strategic implementation planning allowed for a seamless transition without disrupting production.

Beyond its impact on Nucor Memphis, this project demonstrates how targeted SVC control system upgrades can enhance steelmaking efficiency, reduce maintenance costs, and extend the lifespan of power infrastructure. Future work should focus on continue improvement on increasing EAF operational optimization, as well as applying similar control strategies to other steelmaking facilities. By leveraging advanced SVC technologies, the industry can further improve power stability, furnace performance, and overall process reliability in high-demand environments.

REFERENCES

1. E. Martínez, J. Masso, B. Sainz Barajas, J.L. Pepe, Upgrading SVC Firing Circuitry at JSW Steel Ohio Boosts EAF Performance, AISTech 2024 - The Iron & Steel Technology Conference and Exposition, 2024.
2. J. Haros, A. Mariscal, E. Martínez, J.L. Pepe, B. Sainz, Efficient and Reliable Method to Upgrade Static VAR Compensator (SVC) Control Reusing the Solid-State Valves, AISTech 2022 - The Iron & Steel Technology Conference and Exposition, 6–9 May 2022, Pittsburgh, Pennsylvania, USA, pp. 1-3.
3. IEEE Standards Association, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, IEEE Standard 519-2014, 11 June 2014.
4. T.J.E. Miller, Reactive Power Control in Electric Systems, John Wiley & Sons, Inc., New York, NY, USA, 1982.
5. Selection of C-Type Filters for Reactive Power Compensation and Filtration of Higher Harmonics Injected into the Transmission System by Arc Furnaces, Energies, 2020, 13(9), 2330. World Steel Association, “Top Steel-Producing Companies 2020,” 1 June 2021, <https://www.worldsteel.org/steel-by-topic/statistics/top-producers.html>.