Modernization and Upgrade of a Static Var Compensator for an Electric Arc Furnace Application

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INTRODUCTION

Nucor Steel of Utah operates a bar mill production facility in Plymouth, Utah with an electrical feed supplied by the electrical utility via a 138kV transmission network. The voltage is stepped down to 34.5 kV at Nucor's dedicated electrical substation to provide power supply to two 33 MVA AC Electric Arc Furnaces (EAF). To compensate for the electrical disturbances in the network generated by the EAFs, Nucor employed a -36/+72 MVAR Static Var Compensator supplied by GE in 1980. In 1996, ABB replaced the existing GE control system with a more modern ABB VarMach1 control system. In the early 2000s, Nucor began to experience complications with the existing SVC. At that time, Nucor commissioned ABB to perform a system study to investigate the power quality performance of the SVC and to make any resulting recommendations on the modification of the existing SVC configuration as shown in Fig. 1.

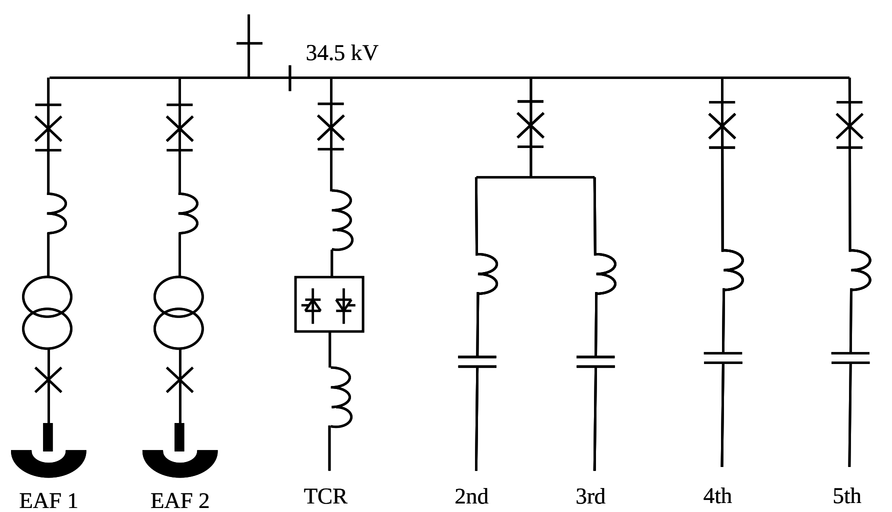

Fig. 1: Single-line diagram, original SVC set-up

SVC SYSTEM STUDIES

In 2005, ABB performed field measurements at the steel mill in order to analyze SVC performance and provide upgrade recommendations. An analysis of the existing SVC performance from the field measurements was made, and a series of digital simulations were performed to determine the optimal topology of an upgraded SVC. These digital simulations, performed using EMTDC, simulated the SVC performance within the existing Nucor electrical system. A series of SVC sizes and topologies were explored, including ABB's SVC Light® (STATCOM) technology. All simulations utilized updated SVC control algorithms and determined the SVC's impact related to power quality characteristics including: flicker, reactive power balance, negative sequence, and harmonics.

Study Conclusions

ABB determined that the mean reactive power consumption of the EAFs was totally compensated by the SVC, resulting in a reactive power exchange between the steel mill and the utility of close to zero. This was an indication that the rating of the SVC was sufficient to maintain the power factor close to unity. However, during stages of the melt with high flicker emission, the reactive power demand from the EAFs was well above the SVC filter rating. The maximum reactive power demand of the EAFs reached 90 MVAR. The limit in the rating of the SVC's capacitive range hindered the SVC control system's ability to efficiently dampen flicker emitted by the EAFs. In order to achieve optimal flicker performance, it was recommended that the SVC be rated between 80-90 MVAR.

The investigation of the harmonic levels in the network also revealed that the 2nd harmonic currents generated by the EAF and in the network were almost equal, while the other harmonics (3rd, 4th, and 5th) were reduced by means of the harmonic filters tuned to these frequencies. The poor damping of the 2nd harmonic currents was due to the characteristics of the 2nd harmonic filter. The capacitors in the 2nd harmonic filter were not rated for the anticipated loads in the system. Also, adding MVARs to the 2nd harmonic filter would lessen the stresses on the existing 3rd, 4th, and 5th harmonic filters. Therefore, it was recommended that the existing 2nd harmonic filter be modified or replaced by a larger, damped filter.

Recommended SVC Upgrade Alternatives

In the study, ABB provided the customer with recommendations for the upgrade of the existing SVC. The first option included the upgrade and modernization of the existing SVC. This comprised of adding 10-18 MVAR to the SVC system rating along with the replacement or modification of the existing 14 MVAR, undamped 2nd harmonic filter with a damped, C-type harmonic filter. The second option involved taking the existing thyristor-controlled reactor (TCR) and 5th harmonic filter out of service and replacing them with STATCOM technology utilizing IGBT-based switching technology as opposed to the conventional thyristor-based switching technology utilized in the existing SVC. The TCR branch and 5th harmonic filter could be replaced with a Voltage Source Converter (VSC) rated +/-46 MVA and a 1.5 MVAR high-pass filter. This approach would achieve the most optimal flicker reduction.

Ultimately, the customer chose to upgrade and modernize the existing SVC with a new thyristor valve, cooling system, control system, and a larger, damped 2nd harmonic filter for a number of reasons. First, at that time the cost implications of the SVC upgrade approach were more favorable compared to the STATCOM option. Also, this approach allows the customer to upgrade the SVC in phases, with the provision available to replace the TCR and update the remaining harmonic filters if the size of the EAFs were upgraded in the future. Importantly, due to the fact that this was an existing steel mill installation rather than a Greenfield project, consideration had to be made for the construction time. The outage time available to perform the SVC construction was extremely limited. Additionally, the aging core components of the SVC (thyristor valve, cooling, and control) could be replaced with their modern counterparts, allowing for easier access to spare parts inventories and field service expertise. Older power electronics and control cards are becoming increasingly difficult to find and available customer support competency for this equipment is shrinking. The combination of these factors resulted in the decision to modernize and upgrade the existing SVC.

SCOPE OF SUPPLY AND SCHEDULE

Scope

In the end of 2006, ABB was awarded a contract to perform the upgrade of the SVC per the outcome of the study and the resulting decision. The scope of the upgrade project included a new ABB MACH 2 SVC control system, new thyristor valve including a new water cooling system for the thyristor valve and a new 2nd harmonic filter rated at 32 MVAR. Additionally, ABB was to perform the necessary engineering and the commissioning of the upgraded SVC. Civil and installation work for the modifications was to be taken care of by Nucor Steel, with ABB supervising the installation process.

The single-line diagram of the upgraded SVC is displayed in Fig. 2:

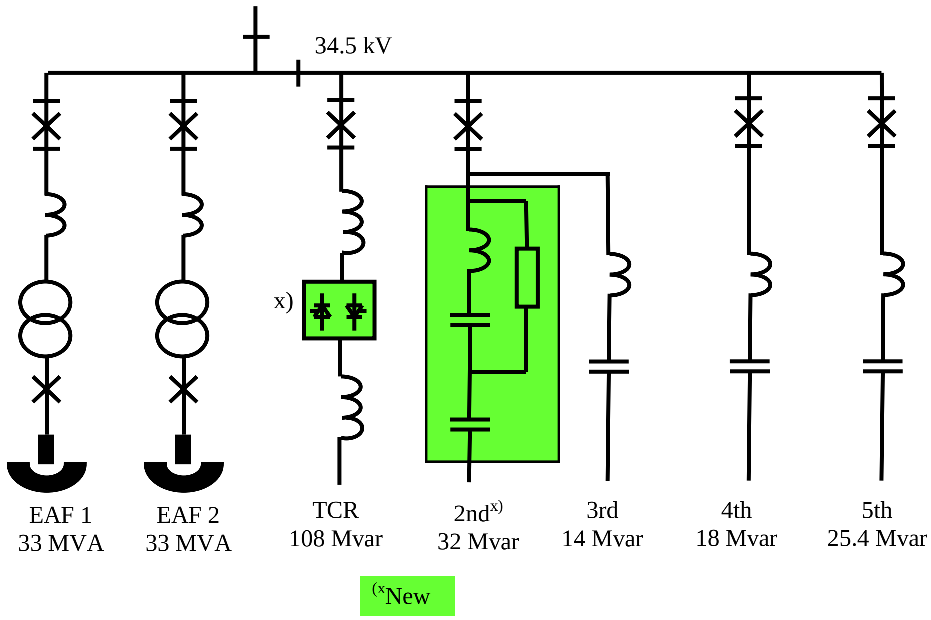

Fig. 2: Single Line Diagram of the upgraded SVC

Schedule

The promised delivery time of the equipment was set to be 12 months. From a planning perspective, it was very important to find a way to perform the upgrade with shortest possible outage of the SVC. This was to limit the impact of the upgrade on the operation of the plant. To minimize the outage time, it was agreed that the new 2nd harmonic filter would be installed in a new location, prior to starting the outage, instead of replacing it in the existing location (Fig. 3). With this filter solution, an outage of 10 days was targeted to perform replacement of control, thyristor valve and cooling system as well as reconnect from the old to the new 2nd harmonic filter.

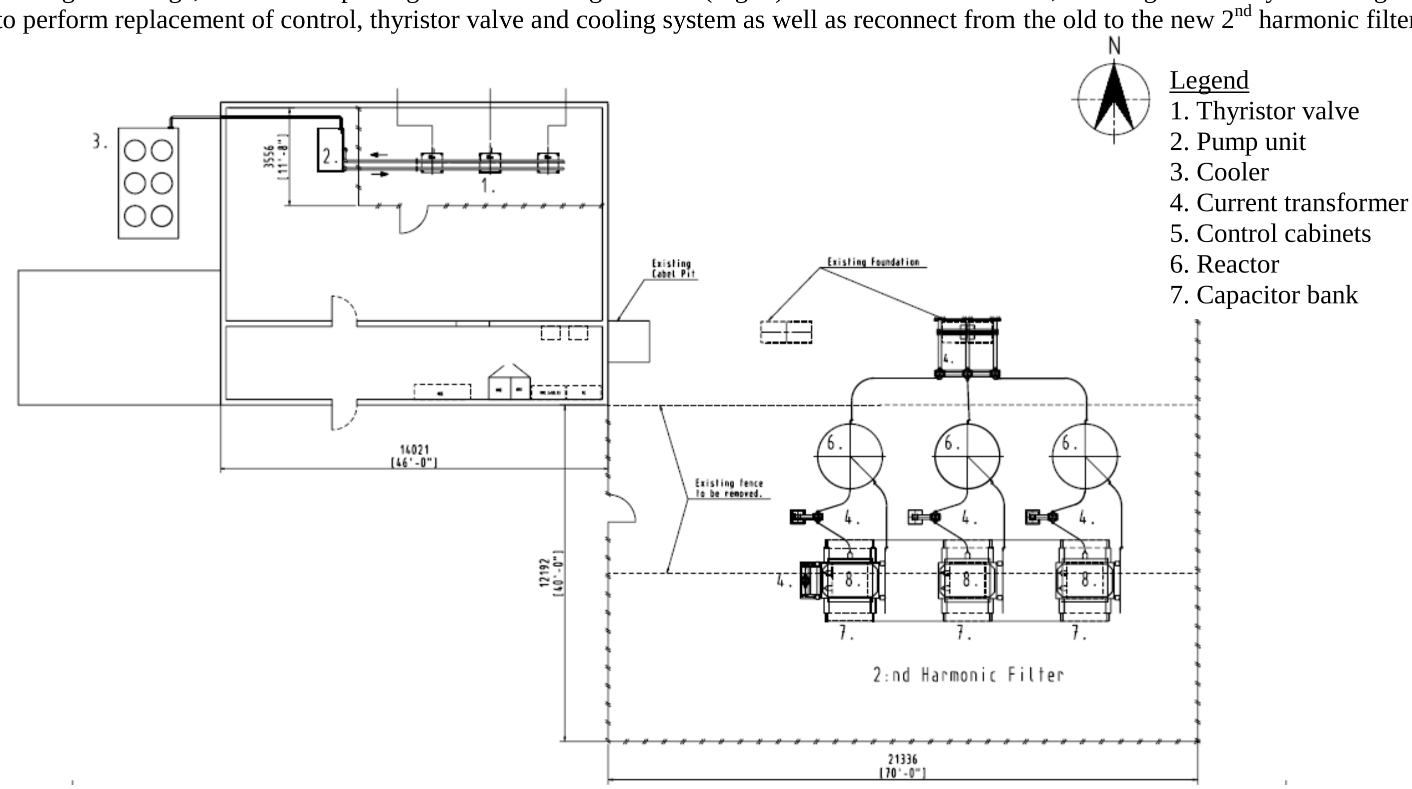

Fig. 3: Layout of the upgraded portions of the SVC. Note the installation of the new 2nd harmonic filter outside the original filter yard. Also note the limited space needed in the existing building as a result of the new, more compact equipment.

Provisions For The Future

The new thyristor valve and cooling system have been rated for a higher TCR rating than what is required by the existing 108 MVAR TCR to accommodate a future upgrade of the plant that will require an increased SVC rating. When a higher rated TCR is required, the rating can be achieved by replacing the reactor coils only. This limits future investment and minimizes outage time in the future.

TECHNOLOGY USED IN THE UPGRADE

2nd Harmonic Filter

The new 2nd harmonic filter has been designed as a C-type filter, consisting of a reactor and a capacitor connected in series in order to reach the required filter tuning (Fig. 4). The filter capacitance is comprised of two capacitor groups in series, with a resistor connected across the tuning reactor and the first capacitor section. The rating of the first capacitor section is chosen so that it forms a series resonance circuit with the tuning reactor at the fundamental frequency. Configuring the filter in this manner results in the fundamental frequency current bypassing the resistor; thus reducing operating losses (Fig. 5).

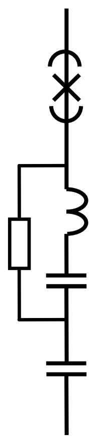

Fig. 4: Principle for a C-type filter

Fig. 5: New 2nd harmonic filter

Control System

The control system is based on the ABB MACH 2 concept, which is a system of both hardware and software, specifically developed for high power applications like HVDC, SVCs, and Series Capacitors. The MACH 2 concept is built around an industrial PC with add-in boards and I/O racks connected through standard type field busses like CAN and TDM. The main objective of the control system is to reduce flicker generated by the load and to improve the power factor in the bus feeder. Control strategies are discussed later in this paper.

The input signals to the control system are generated in current and voltage transformers that are located in the substation. These are used by the control system for control, supervision and synchronization purposes. The control system processes the input signals, calculates the phase-angle for triggering of thyristors and converts them to control pulses for the TCR thyristor valve. These pulses are transmitted to the Valve Control Unit (VCU) and from the VCU to the valve via optic fibers.

The SVC can be controlled from the SVC control room by an operator workstation (OWS) based on a personal computer (Fig. 6, 7). As “back-up” to the OWS system, there are two pushbuttons in the front of the control cubicle for SVC-ON/OFF control. The operator’s interface is controlled by InTouch software, a product of Wonderware, running on the OWS computer. This computer also handles the event handling. All event, alarm and fault lists are displayed on the OWS. The OWS PC is connected directly to the control computer via a LAN network. The new control system’s remote access capability provides the ability to assist in failure investigations and to take corrective actions remotely.

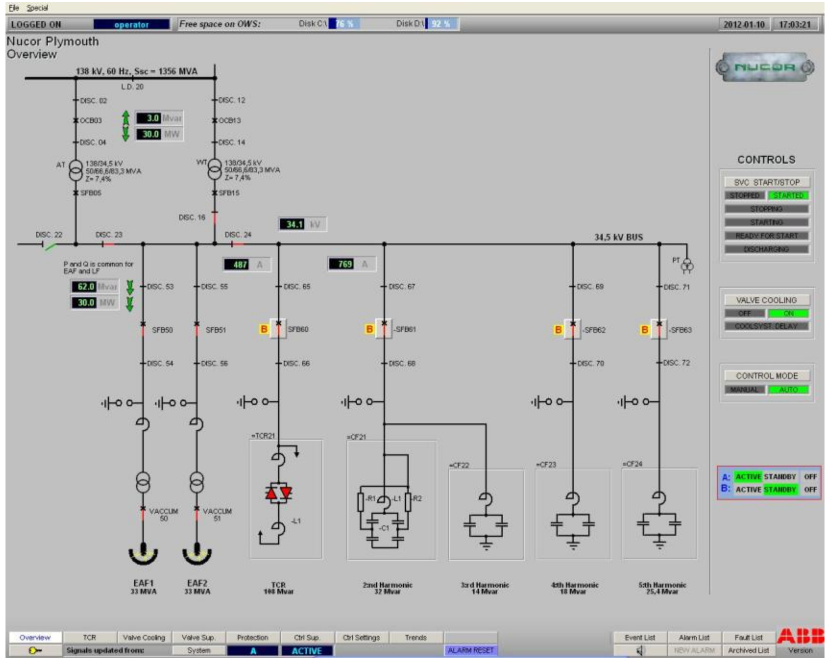

Fig. 6: SVC control room (MACH 2 and OWS)

Fig. 7: OWS view: Single-line diagram

Control Strategy

The aim of the SVC is to control the power factor on the incoming line, stabilize the voltage at the furnace bus, and reduce the flicker at the point of common coupling (PCC). The automatic control system consists of an open loop phase-wise susceptance regulator and a closed loop susceptance regulator. All regulators are located in the MACH 2 computer.

Open loop control (Flicker regulator)

The main objective of the open loop regulator is to generate fast susceptance references for the SVC in order to suppress flicker and phase unbalances. The SVC compensates for the EAF currents consisting of the reactive part of the positive phase sequence current, and both the active and reactive part of the negative phase sequence current. Hence, the voltage drop and fluctuations over the AC network are minimized.

Closed loop control

In addition to the open loop control there is a closed loop control. Three different control strategies can be used:

- Reactive power control
- Power factor control
- Voltage control.

Reactive power control

The purpose of reactive power control is to keep the reactive power in the incoming feeder close to zero and thereby a power factor close to unity in the incoming EAF bus feeder.

Power factor control

The active and reactive network powers are calculated and the actual power factor (P.F.) is derived. Based on the P.F. setting, the reference of the reactive power (MVAR) is set to correspond to the required P.F.

Voltage control

The purpose of this control is to keep a desired voltage in the EAF bus feeder. With this control strategy, the output from the SVC can be either capacitive or inductive, depending on voltage. (The power factor requirement cannot always be fulfilled with this strategy.)

Thyristor Valve

The thyristor valve consists of three single-phase assemblies. The high power thyristors are electrically fired (ETT) and the energy for firing is taken from snubber capacitors in the valve. Thyristor firing orders are communicated via optical light guides from the valve control unit. This type of system is normally called “indirect light firing”.

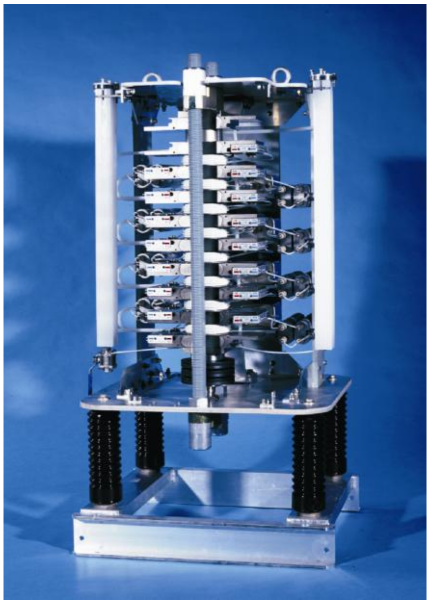

Fig. 8: Thyristor stack, one phase out of three

Fig. 9: Valve cooling system

The thyristor valve employs series-connected 5 inch thyristors, water-cooled, together with associated snubber circuits, thyristor electronics, heat sinks and clamping arrangement. The valve is designed with free standing single assemblies, each with a stack of BCT (Bi-directionally Controlled Thyristors) (Fig. 8). In the BCT, anti-parallel thyristors have been integrated on a common silicon wafer; therefore, only one thyristor stack is required per phase. With this arrangement, only half the number of thyristor housings and heat sinks is needed. The number of components in a valve and the number of connection points for the water cooling is reduced. Thus, reliability is improved while manufacturing and maintenance expenditures are minimized.

Between thyristors and at the top and the bottom of each stack, heat sinks remove thyristor heat losses. These also serve as an electrical connection between the thyristors. Thus, the thyristors are cooled from both sides. The coolers are connected, each level in parallel, to a water piping system. The inlet coolant also cools the snubber resistors. The cooling media is a mixture of water and glycol with low conductivity. The water cooled system is more reliable, while requiring less maintenance and less space compared to the original air cooled thyristor valve.

Thyristor Valve Cooling System

The thyristors are connected to high voltage potentials, where the heat sinks are used as conductors between the components. This mechanical setup where the heat sinks are in direct contact with energized parts of the valve requires that the cooling media is of non-conducting type. De-ionized water is used as cooling media in a closed-loop cooling system. The water is flowing through all heat sinks and is cooled by outdoor heat exchangers. A small part of the water flow is continuously filtered and de-ionized to ensure low conductivity of the water.

CONSTRUCTION PHASE

The main targets of the construction phase were to minimize the scheduled outage and to cause minimal production impact. With these requirements in mind, the upgrade was scheduled for mid-March 2008. This was the time set by the yearly outage period for the steel plant. A preparatory site visit took place approximately 1 month prior to the planned outage. ABB provided a list to the customer of activities that could be performed prior to the outage. The goal was to complete as much of the work as possible prior to the scheduled outage. After this joint review, the Nucor Steel crew had a few weeks to perform the preparation work.

Approximately one week prior to the outage, ABB's supervisor again joined the Nucor staff at site to finalize the preparation and plan for the outage. Partially dual working shifts were employed to minimize the outage time. Testing and commissioning work was performed in parallel with the upgrade installation to the greatest extent possible. A very short period was needed for the pure commissioning upon construction completion. With the detailed preparation done jointly by ABB and Nucor Steel combined with the shift work, the upgrade was completed and the SVC was back in service after only a 10 day outage, as scheduled.

The key to the successful performance of the work at site removing, installing and testing under time constraint was the cooperation between the ABB and the Nucor Steel teams. Preparatory work done prior to the outage made it possible to have full control of the logistics with needed recourses, equipment and material supply.

Fig. 10: (Left): Old GE thyristor valves from 1980. (Right): New ABB thyristor valves being installed next to the base of the old valves.

SVC UPGRADES: A COMMENT

Technology development, especially of thyristor valves, introduced the Static Var Compensator (SVC) concept in the mid-seventies. This resulted in a significant number of commissioned SVCs throughout the world, starting in the early eighties and continuing today. SVC technology is now well-proven. The design life of an SVC is typically 30 years, consistent with other high voltage high power electronic devices. Referring to the first SVCs commissioned, which now have 20-30 years of operation, it is reasonable to expect that many are in need of refurbishment to some degree, more or less comprehensive. Often the reason is lack of spare parts and competence relating to both owners and suppliers of SVCs.

In many cases, the need for SVCs to remain in operation, due to system stability, voltage support, or up keeping/improving power quality in the grid has increased in the years following commissioning. Hence, the alternatives are either to replace a vintage SVC with a new unit or to upgrade the existing one. Upgrading often has the benefit of lower cost as well as less time expenditure.

SUMMARY

An upgraded, modernized SVC rated at 34.5 kV, -18/+90 Mvar has been commissioned at the Nucor Steel of Utah facility in Plymouth, Utah. The steel plant is fed from a 138 kV utility grid. The purpose of the SVC is to compensate for electrical disturbances generated by two electric arc furnaces (EAF) in the plant rated at 33 MVA. These disturbances are due to the stochastic nature of the EAF resulting in the dynamic consumption of reactive power in the Nucor electrical system.

The existing SVC thyristor valve, cooling system and control system were upgraded with modern technology. Additionally, the 14.4 MVAR, undamped 2^{nd} harmonic filter was replaced by a 32 MVAR damped filter of C-type configuration. All of these components have been designed and rated to accommodate a future SVC upgrade with minimal modification.

The upgraded SVC was successfully commissioned in 2008 within the short, allotted outage window. Since commissioning, utility complaints have ceased and the upgraded SVC has positively contributed to the steelmaking process.