Applying SVCs on Distribution Systems

Kerry Diehl, *Member IEEE*, John A. Diaz de Leon II, *Senior Member IEEE*, and Manisha Ghorai, *Member IEEE*

Abstract - Many loads located on utility distribution systems adversely affect power quality on both the transmission and distribution systems. Non-linear inductive loads can cause unacceptable levels of voltage sag and/or flicker which affect both the event initiator and all other utility customers receiving power from the same distribution substation.

Static VAR Compensators (SVC) are shunt-connected devices FACTS which have been routinely applied to address transient voltage sag and flicker problems on transmission networks. This paper discusses the advantages of using SVCs to address distribution-level problems via direct connected SVCs.

Case studies demonstrate the impact of using SVCs to address problems arising from the use of large non-linear distribution loads. Topics covered include: location tradeoffs, voltage sag and flicker mitigation, harmonic current and voltage issues, and design considerations.

I. TERMINOLOGY

FACTS: Flexible AC Transmission Systems.
SVC: Static VAR Compensator
STATCOM: Static synchronous Compensator

II. INTRODUCTION

Traditionally, SVCs have been have been applied to a variety of utility problems such as post fault voltage recovery and system voltage stability. Constructed as large reactive compensation devices (hundreds of MVAR) they provide transient voltage recovery voltage support, and low-speed voltage control, using high-speed thyristor-based power electronic switches to dynamically switch capacitor banks and adjust reactor banks.

The same technology can also be applied to solve distribution system voltage stability problems with smaller SVCs operating directly at distribution voltages.

Distribution-level SVCs are enhanced by two technology trends. Continuing advances in power semiconductor technology (i.e., improved SCR and diode withstand voltages at acceptable operating loss levels) make medium voltage TSC valves increasingly compact and efficient. Continuing advances in microprocessor control technologies have steadily improved the cost versus performance characteristics of highly flexible, fully digital SVC control systems.

Concurrently competitive world-wide markets require all industrial and commercial facilities to become more sophisticated, demonstrate higher operating rates and better availability, while constructing or expanding operations in the most cost-effective manner possible.

Increasingly cost-effective high-speed VAR support reduces load-induced voltage changes and improves industrial output: this combination is driving end-user demand. Utilities, challenged to improve delivery quality on weak, dispersed distribution systems or to maintain acceptable delivery levels near disturbing loads such as large motors or other large non-linear loads also find high-speed VAR support extremely valuable.

A distribution-level SVC is a cost-effective solution to address the majority of such power quality problems. This paper delves into the technology design and applications experience behind the American Superconductor SVC for distribution systems. It also reviews decision-making considerations associated with employing distribution-voltage SVCs

A. Distribution VAR Compensation

An SVC for distribution or industrial applications typically solves load- induced problems (such as power quality issues or customer operations). The SVC essentially "cancels out" the impact of the load on circuit voltage stability by providing flicker and voltage sag control for these applications. The duty cycle frequency for these applications can range every 1/4 second to once a day or less.

Directly-coupling the SVC to the line eliminates requirements for transformers, buildings, and environmental conditioning, drastically reducing costs. SVCs can be mounted in substations or on regulator racks or enclosed if required by environmental conditions.

B. Economic Considerations

Power Engineering must be responsive to first cost and operating economics. Installation of dynamic VAR compensation to mitigate voltage instability at distribution voltage has two main alternatives: reducing or relocating the load requirements, or lowering the source impedance at the point of connection through more traditional means.

Load-side changes can eliminate the requirement for dynamic VAR compensation. Examples include: utility refusal to serve the load at an affordable price, reduction in customer load at the location (moving elsewhere), or employing technologies (such as variable-frequency drives [VFDs]) to reduce loading requirements.

Utility, or system-side, alternatives for improving voltage stability include power system reconfiguration. Power system reconfiguration can occur by lowering of the source impedance at the point of common coupling (PCC) or, more rarely, by increasing the impedance at the PCC.

Lowering the source impedance strengthens the system to the extent that the load-induced voltage instability ceases to be objectionable. It starts with location-specific analysis, and may require changes ranging from distribution circuit re-conductoring, to transformer change-out, or transmission circuit construction. The result is more stable voltage for all customers.

Increasing source impedance, typically with current-limiting reactors, is less common and increases the voltage instability for the affected customer while restoring stability for the remainder of the circuit.

When evaluating SVCs against other approaches, three factors should be considered during valuation: first cost, supervisory and maintenance costs, and recovery value. The last is because the ability to easily relocate an SVC creates a new, time-dependent source of value to the owner.

First cost assessment is easily understood. Appropriate SVC costs include interconnecting breaker, system siting, assembly and installation, and communications infrastructure. Most SVCs can be installed and operating in less than a week with a 3-person crew if the site has been prepared.

SVC supervisory and maintenance costs can be limited by design. SVCs can include remote monitoring and alarming capabilities and self-diagnostics to reduce costs. Third party monitoring provides additional opportunities to reduce costs. Modular designs allowing for repair by medium-voltage qualified linemen after several hours of training can reduce costs still further.

The mobile nature of an SVC requires careful evaluation. If investment is required to address problems caused by a limited number of customer loads, the possibility of "losing" these loads prior to end of the asset life must be evaluated. Similarly, if an SVC is considered an "interim upgrade" until load growth caused a power system upgrade, valuing the future redeployment of the SVC is appropriate. As an asset, an SVC resembles a reusable transformer (though lighter and easier to move).

III. DISTRIBUTION VOLTAGE SVC THEORY

A. SVC Elements

Classic Thyristor-Switched (Thyristor-Controlled) Reactor-based (TSR/TCR) SVCs have very limited distribution application: most loads are inductive, TCR harmonic levels are unacceptable, and the inductance required for small TCRs is generally non-economic.

Distribution SVCs are typically binary-switched TSCs, operating "static switches" or "valves," with separate valves for each phase and capacitive combination. They commonly have 6, 9 or 12 static switches (arranged on a 2x3 –phase, 3x3-phase or 4x3-phase basis), operate in a binary-switched mode, and provide 3, 7 or 15 levels of capacitance.

Two anti-parallel static switch designs are used multiple anti-parallel pairs of thyristor/ thyristor or thyristor/diode combinations are arranged in series to meet voltage requirements. All series elements must be switched on or off ("gated") at the same instant to avoid catastrophic failure. Choice between the two switch designs is based on reliability, cost, and thermal considerations. In-field performance between the two design types is generally indistinguishable.

B. TSC Operation

Static capacitor switching with a thyristor/diode valve is shown in Figure 1 Thyristor Switching, below. Single-phase line voltage is shown in dark blue, and single-phase current is shown in light blue/green. The diode portion of the switch maintains the capacitors at the negative peak voltage, charging the capacitors to the negative peak voltage when the SVC is first connected to the power system, and maintaining the capacitors at the negative peak voltage each cycle thereafter.

The valves change state once per cycle when the line voltage recedes from the negative peak voltage and the current is just past zero. When inserted, the voltage differential between line and capacitor is small and inrush negligible. When removed, the capacitor remains charged to the negative peak voltage, ready for possible re-insertion at the next switch point.

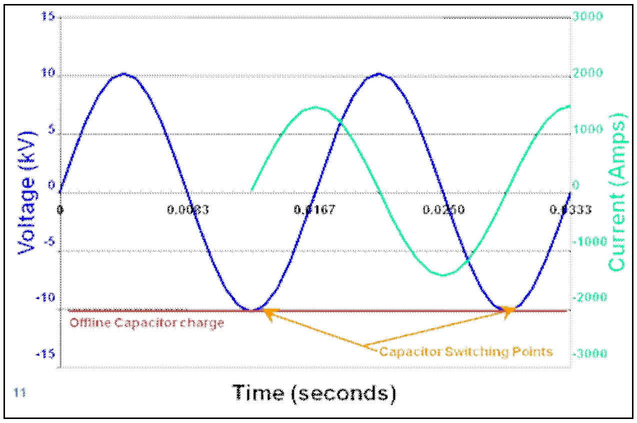

Figure 1 Thyristor Switching

C. Limitations

Three fundamental characteristics limit TSC capability: capacity limitations, sag limitations, and harmonic limitations.

Capacity limitations: SVCs are passive, rather than active network devices. Applying capacitance at a point lowers the resonant frequency according to the formula:

$$f_{res} = \frac{1}{2\pi} \cdot \frac{1}{\sqrt{L_{source} C_{svc}}}$$ [1]

Where L is the inductance of the circuit in Henries and C is the capacitance of the circuit in Farads. Experience suggests the minimum resonant frequency should remain above 150 Hz.

Sag Limitations: The reactive power output of an SVC is a function of the square of the voltage as indicated in the following formula:

$$Q = \frac{v2}{x}[VAR]$$

Where V is the voltage at the SVC terminal in volts, and X is the reactance of the SVC in Ohms. As the voltage falls, the SVC output decreases by the square of the voltage. In load-directed motor applications this matters little since the load's kVAR requirement falls at the same rate. However, for situations requiring effective VAR output at very low voltages, an SVC may not be the best solution. For these types of applications, a STATCOM, whose output varies linearly with voltage, may be a more effective solution.

Harmonic Limitations: Thyristors are effectively gated (switched) rectifiers. Once gated, each device remains "on" until the current passes through or close to zero ("latching current"). Every device is susceptible to rapid current fluctuations, at low current levels, until it has transitioned from being fully "on" to fully "off." Design minimizes the di/dt present at each device and site-specific power system analysis is highly recommended to minimize valve vulnerability (see: *Harmonic Generation/Mitigation* below).

These effects are compounded by the series design of these SVC valves. The "gate drive" operating each valve has highly precise timing to operate all series elements simultaneously while preventing individual elements from turning off at intermediate harmonic levels.

D. Transient Voltage Control

A load-side focused distribution SVC uses both voltage and current sensing to precisely calculate the VAR requirements necessary to offset load-induced voltage changes. SVC controls measure single phase voltages at high speed, digitizing the resulting data for analysis and calculation. One or more load current phases are also measured and digitized. SVC programming includes the X/R ratio at the point of connection.

Analysis of single-phase voltages and currents allows rapid and precise calculation of both the real (kW) and reactive (kVAr) elements of the load. Voltage is rapidly restored to the same level as would occur without the load by multiplying the voltage change due to the load by (1+R/X) at the SVC point of coupling and inserting the appropriate amount of capacitance. [i]

In this manner, the SVC offsets the impact of the load on voltage stability, allowing existing voltage regulation equipment on the power system (capacitor banks, load tap changers, etc.) to operated without modification.

Substantial control system flexibility allows the SVC to operate symmetrically or independently on all three phases, maintain a fixed voltage target (either in lieu of, or in addition to load flicker mitigation), and control additional switched capacitors or reactors.

E. Harmonic Generation/Mitigation

Unlike TCRs, TSCs do not generate harmonics. However, in operation an SVC applies (typically 7 to 15) rapidly varying levels of capacitance at a single point on the power system. This raises two possibilities: first, temporary harmonic resonances can be created within the SVC or near-by cap banks at one or more capacitance levels, and second, that the SVC may become a sink for harmonic currents for external harmonic currents.

These concerns are justified for distribution voltage SVC applications: inspection of IEEE-519 shows substantially higher harmonic levels are allowable at lower voltages and fault currents. AMSC experience also suggests many distribution circuits are above IEEE-519 levels.

[1] Source resistance is ignored.

Table 10-3—Current Distortion Limits for General Distribution Systems (120 V Through 69 000 V)

Maximum Harmonic Current Distortion in Percent of I_L

Individual Harmonic Order (Odd Harmonics)

I_{sc}/I_L	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd harmonic limits above.

Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.

where
I_{sc} = maximum short-circuit current at PCC.
I_L = maximum demand load current (fundamental frequency component) at PCC.

Figure 2 Table 10-3, IEEE 519[ii]

To ensure reliable operation with a minimum of unintended consequences, a power system/ harmonic analysis must be included in all SVC projects.

Thorough study requires significant amounts of information on the including: source impedance at the PCC, nearby capacitor bank locations and characteristics, background harmonics, and detailed load-side data. Where information is limited, prior experience is used to develop heuristics for areas such as background harmonics, VFD, and soft-starter characteristics. This information is used to develop a 3-phase system model used in subsequent analysis. The analysis is parametric: all SVC states must be considered. For balanced applications this is commonly 3, 7 or 15. For unbalanced applications this can grow rapidly to 13, 91, and 695 possible states.

Harmonic currents and voltages predicted by analysis are compared against two metrics: the first is the utility's power quality requirement (typically IEEE-519 and/or IEEE-1453). The second, internal to AMSC ensures harmonic distortion within the SVC remains low enough for reliable operation.

Once identified prospective harmonic problems are addressed based upon specific circumstances. Methods include: modified SVC filtering, software adjustments, changing step sizes and, additional harmonic filtering.

IV. DISTRIBUTION APPLICATIONS

AMSC SVCs have been installed at almost 100 locations to solve distribution-level problems including voltage sags and power quality issues caused by loads that are large in relation to the available fault current. The examples discussed below present surrounding circumstances, benefits for all parties and unit performance where permitted.

A. LOAD-INDUCED TRANSMISSION SAGS

Piedmont EMC, located in Hillsborough, North Carolina receives power delivery from an IOU via a radial 44kV line. The 44 kV line passes two Piedmont 44/12.47 kV substations before terminating at a 44/4 kV substation dedicated to a pipeline customer immediately adjacent to the substation.

When the customer starts either motor without an SVC present, a sag exceeding 10% is observed on the 44 kV line at both of other substations serving residential loads. The 5 kV pipeline bus sags to approximately 0.83 PU during starts: this voltage level is adequate for a prolonged start, but extends the duration of the sags seen at the other two substations.

This customer has been operating since 1973. But sag-related complaints grew as residential load increased at the two adjacent substations – and as EMC member dependence on digital electronics grew.

First efforts to address motor starting sags used fast-switched capacitors. Classic capacitor problems were experienced: switching transients when capacitors came on-line, sags when VAR demand outstripped supplied capacitance as the capacitors were energized, and over-

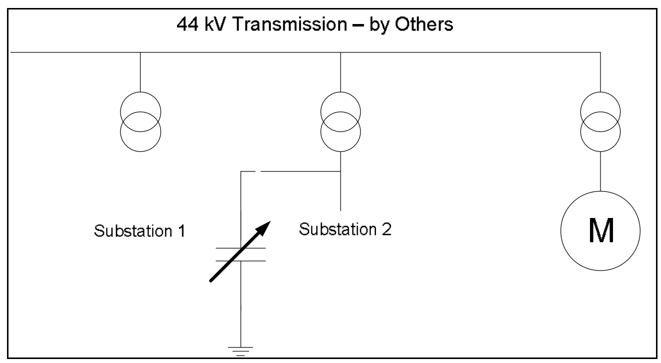

Figure 3 Piedmont EMC 1-line

voltages prior to capacitor switch-off. An excellent discussion of the alternatives subsequently considered for this application is contained in the paper by Ed Thomas[iii].

Reduced-voltage soft-starting was considered. The limited benefits and customer concerns about starting torque eliminated this alternative. Other alternatives considered and discarded included series capacitors.

Once a distribution-voltage SVC was chosen, Piedmont considered where to locate the SVC(s). Their careful analysis led to highly pertinent observations:

Locating an SVC on the 5 kV bus provides the best isolation due to the impedance between the 5 kV station and the other two EMC substations. However, Piedmont had no other 5 kV substations, and a 5 kV SVC would not be reusable.

Placing the SVC directly on the 44 kV line was considered and discarded as being more expensive.

Transformation would be required, and the total price of the system could easily double.

Placing the SVC on one or more 12.47 kV buses was studied. Simulation suggested that use of a single system at the closest substation would yield results comparable with individual SVCs at each substation for about half the cost. This alternative was chosen.

The SVC selected for this application is rated at 8.4 MVAR, 3-phase, and provides 7 levels of capacitive

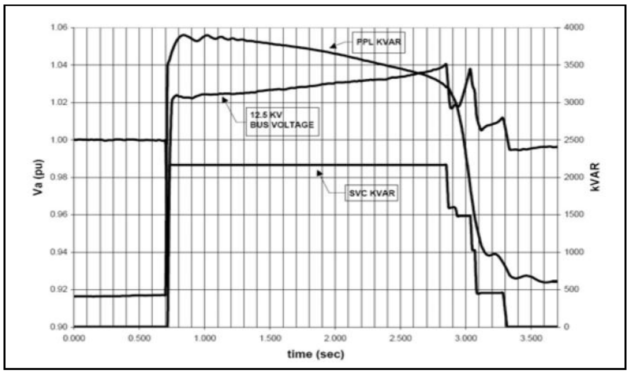

Figure 4 Piedmont Motor Start

support in increments of 1240 kVAR. This step-size equates to a 3.2% step voltage change at constant voltage, and was chosen using the GE Flicker Curve based on the frequency of motor starts. Subsequent field measurement shows the effective voltage resolution of the unit is below 3%, since VARs are applied in response to ramp voltage changes.

The unit was installed in 2004. Between 2004 and 2007 it suffered one short outage due to a control board. In 2008, Piedmont elected to upgrade to a new controller and the unit continues to operate.

Figure 5 PEC SVC in Substation

Piedmont's careful consideration of alternative SVC locations resulted in a system with substantial residual value. Taking responsibility for the SVC pad and wiring they minimized costs and developed an initial familiarity with the SVC. While AMSC provided startup services, and specialty maintenance (e.g., controller upgrade), most maintenance is performed by PEMC line crews.

B. REMOTE LOAD APPLICATIONS

Scrap recycling is a growth business. Back-end recovery is highly precise with sophisticated separation and recovery of ferrous and non-ferrous metals, glasses, and lastics. Everything gets recycled and reused – with the xception of the "fluff" –seat stuffing.

'ront-end preparation operations use very large motor-riven hammer mills to shred autos, trucks and ppliances to small pieces over 10-20 seconds. The AC notors used are multi-pole, low-RPM wound-rotor notors with liquid rheostat controllers. The resistive ature of this starter/ motor design allows for low motor tarting currents.

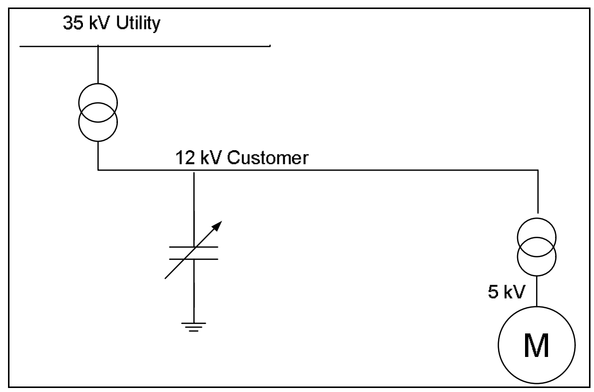

Figure 6 Pacific Steel Shredder

Operating shredders are taken from idle current up to 2.0 full load current and back several times per minute to meet hammer mill loadings. Occasional jams lock the rotor, causing substantial voltage sags.

AMSC has encountered AC shredders ranging from 1,500 to 7,000 HP, at 4kV to 13.8 kV. Most are upgrades to existing locations or a shredder added to a recycling site. An SVC becomes an option when voltage drop calculations indicate insufficient fault current at the site.

From the utility viewpoint, an SVC represents a lower first cost than system upgrades. If customer purchased, it eliminates the risk of not recovering the costs of a customer-specific power system upgrade. Shredder operators soon learn SVCs can maintain constant voltage at the motor terminals, boosting motor toque under load, and boosting output, better than any other technology.

Pacific Steel and Recycling called in early 2008. They had purchased and installed a 3,000 HP shredder for use at an existing site in Idaho and the utility refused to provide service for the shredder until flicker levels could be held below 1% on the only 35 kV line in the area.

The power system (see Figure 6 Pacific Steel Shredder) reflected an incremental addition to an existing location. The customer was served from the 35 kV line. The facility had dual transformation: from 35kV to 12kV; then from 12 kV to 4 kV. The increased source impedance at the motor terminals reduced the prospective sags on the utility lines, and reduced the prospective operating torque.

Physical SVC placement reflects substantial prior shredder experience. Never locate an SVC in the vicinity of a shredder unless it is enclosed: the mills throw highly conductive materials and large projectiles long distances.

Placing the SVC at 12 kV located it about 1000 feet from the shredder, eliminating the need for (and cost of) an enclosure. It also created a non-optimal solution for the customer: if current and voltage are measured on the 12 kV bus for cycle-by-cycle VAR compensation, the voltage droop caused by the last (5 kV) transformer, will not be fully corrected at the motor terminals. To remedy this, the load CT is placed in switchgear at the motor terminals, and a pre-existing control algorithm used to rescale and phase-shift the 5 kV delta current to allow full correction by the SVC on the 12 kV power system.

The SVC was sized at approximately 4 MVAR and adjusts VARs in 300 kVAr increments to maintain voltage on the 12.47 kV within 1.2% ($\Delta V/V$), resulting in a $\Delta V/V$ at 35kV of less than 0.8%.

The unit was placed in service in July 2008. Voltage stability results have been better than those promised. Adding the SVC has increased customer energy consumption by about 20%. The utility assumed that Pacific Steel had changed the settings on their liquid rheostat motor control: Pacific Steel indicated that the settings were not changed. The increased power consumption reflects the steady (and higher) motor terminal voltage. The customer sees a motor that stays at speed longer and shreds more tons per shift. The utility does not see blinking lights.

Often the value of a distribution-voltage SVC is based on its ability to address a geographic disparity: where load density (mw/sq. mile) is uniform, a well-designed power delivery system addresses all requirements. Where load density is uneven, specifically where load density is much larger in a specific sub-region, a distribution-voltage SVC becomes a viable solution.

C. MULTIPLE LOAD APPLICATIONS

Prior examples address flicker mitigation for single loads. REA Energy a 5,000 member co-op headquartered in Indiana, Pennsylvania had a different problem: multiple coal-mining customers located on a single circuit.

The two mining operations are located in the same area, approximately 3 miles apart. Each uses continuous miners to push several AC motor-powered cutting heads into coal seams to remove material, which is then carried from the mine face by integral conveyors. Profitability is proportional to output, and miners push the cutters as close to locked rotor as possible before withdrawing from the face to regain speed.

For flicker mitigation purposes each site is modeled as a series of independent motor loads, with large motors (powering cutter heads) moving from idle to near-locked rotor conditions while other motor loads (conveyors equipped with reduced voltage soft-starters) come on and off randomly. Steady state loads such as mine ventilation and pumping systems are ignored for flicker analysis, but included for power flow, power factor, and harmonic analyses.

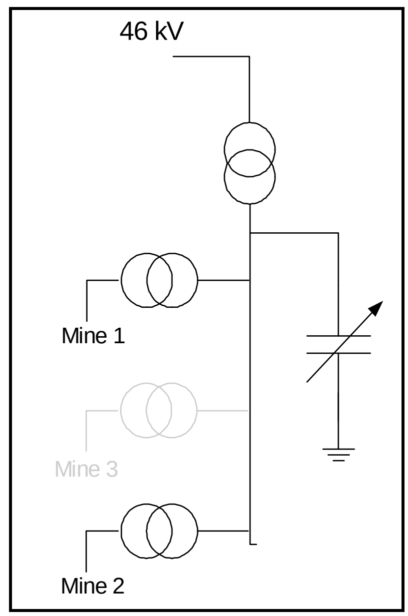

Figure 7 REA SVC 1-line

One mine was already in service and customer complaints had increased. The second mining company had requested service, and both had indicated plans to increase load. REA had also received notice from a third planned mining operation that would locate in the same area. All would be located on a single 12.47 kV circuit, fed from a 46 kV substation.

Considering how to address the flicker, REA was aware that typical small mines in Appalachia last 3 to 7 years. Even if reconductoring the line would yield acceptable flicker mitigation, it would also result in a permanent high ampacity upgrade to a circuit for a maximum of 7 years use.

By choosing an SVC, REA was able to reduce first cost and still have a reusable asset when mining ceases. But two additional concerns surfaced during planning: (1.) whether each mine required an SVC, and (2.) how the possible addition of a third mine on the circuit would affect the SVC(s) purchased.

Since the circuit is not dedicated to the mining customers, other customers, see flicker from mining operations. Analysis of the line impedances between mines showed that locating the SVC immediately to the source side of the first mine, and then correcting to levels below the IEC flicker table (Table A. 1, IEEE-1453)[iv], would leave flicker at the respective mine entrances at acceptable levels. Thus one SVC could be used to treat all mining loads.

Flicker caused by the first two mines could be addressed by using a 7-step SVC rated at about 2.4 mVAR. Prospective addition of the third mine would require additional capacity. Addition of the third mine would increase maximum flicker levels and require a larger SVC than was required to serve two mines.

This could be solved by designing the SVC for in-field expansion if the third mine came online. AMSC SVC installations are designed for field expandability: in this case the system can be expanded to 15-step unit with a rating up to 6 mVAR by the addition of 3 static valves and suitable capacitors. This design proved useful: the third mine has not started, and REA did not invest in unused capacity.

D. DISTRIBUTED GENERATION[v]

PacifiCorp approached AMSC in 2003 about a voltage flicker problem they had encountered. Large extruders, located in an animal feed preparation facility, were the source of the problem. Although the large motors were equipped with soft-starts to reduce starting inrush, the motors were heavily loaded and frequently stalled, a condition soft-starts could not address.

In addition to the feed preparation facility, a low-head hydro generation facility was located on the same circuit. Fault current increased significantly when the local generation was available. When it was unavailable the circuit fault current dropped to levels where the flicker became visible and objectionable.

The SVC system was placed in service in 2004 and remains in service today.

Power system analyses in this case resembled those conducted for transmission-level SVCs. In addition to the harmonic analyses previously discussed, the response of the SVC – and the resultant power quality – had to be considered under all the source impedance conditions that would be encountered on the circuit.

AMSC has subsequently encountered similar situations involving distributed generation and expects these encounters to increase as distributed generation continues to grow. Common issues include: protecting the circuit from flicker (as demonstrated in this case), ensuring that sudden generation loss does not result in unacceptable circuit sags, and optimizing power flows.

Figure 8 SVC with Feed Mill

The economics for SVC application with distributed generation parallels those discussed above for customer loads. Adding an SVC allows use of larger distributed generation than otherwise possible at a given location.

The customer-side engineering alternatives include locating the generation elsewhere or using smaller generators. Since operator economics are a matter of scale (within bounds, bigger is better) and location (convenient to fuel, or specific geological features), SVCs receive early consideration.

Utility engineering alternatives require reducing the source impedance at the PCC. Unless required due to ampacity concerns, they are seldom attractive. This is further explored in the referenced paper by Waters and Hansen [v].

V. BIOGRAPHIES

Kerry N Diehl has been involved more than 75 SVC projects. He joined AMSC in 2006 when PQS, (which he helped found) was acquired, and is Director SVC Products. Kerry graduated from Lehigh University and Carnegie-Mellon University. Prior to PQS, he held positions at PNR & Assoc., Duquesne Light, Associated Communications, Westinghouse Electric and PHB. His background includes engineering, business development, management consulting, and marketing.

John A. Diaz de Leon II, PE joined American Superconductor in 1999 after working for Alliant Energy/Wisconsin Power and Light Co. for 20 Years. He earned his Electrical Engineering degree from the University of Wisconsin. His current position is Consulting Engineer in Network Planning and Applications. He performs planning studies to analyze transmission and distribution systems for voltage, capacity, stability, transfer capability, harmonic and power quality problems. He also conducts studies to analyze wind farm interconnection requirements that include LVRT and HVRT capabilities, harmonic and power quality problems, voltage regulation, and power factor control

Manisha Ghorai joined American Superconductor in 2006 after graduating from the University of Wisconsin with her degree in Electrical Engineering. She currently works on the Network Planning and Applications Team. She performs studies where she analyzes transmission and distribution system problems such as for voltage collapse, transfer capability, wind farm interconnection, harmonic, and power quality problems.

REFERENCES

[i] RS Kemerer, LE Berkebile, "Directly Connected Static VAr Compensation in Distribution System Applications", *IEEE Industry Applications Magazine*, Vol. X, pp xxxx-xxxx, 1996.

[ii] IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, IEEE standard 519, 1992

[iii] ES Thomas, "Appplication of Adaptive VAr Compensation for Transmission System Flicker Correction", *IEEE Industry Applications Magazine*, Vol X., pp xxxx-xxx, 2005

[iv] IEEE Recommended Practice for Measurement and Limits of Voltage Fluctuations and Associated Light Flicker on AC Power Systems, IEEE standard 1453, 2004

[v] T Waters, D Hansen, "Addressing 'Soft System' Dynamic Issues: Principles for Forming Sound Utility Practices", *IEEE Power & Energy Magazine*, Vol X., pp 40-46, Jan/Feb 2006