The Application of a DSTATCOM to an Industrial Facility

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***Abstract*—This paper describes the application of a Distribution Static Compensator (DSTATCOM) to an existing industrial facility for voltage flicker mitigation during the starting of a large motor. Traditional methods are discussed for comparison. The performance of these methods and the DSTATCOM are compared using computer-based modeling. Additionally, the cost and reliability are presented to determine the most viable solution to this or other similar problems. The DSTATCOM performs well, should have acceptable reliability and be cost competitive with other solutions. Clearly, this will become a very powerful power system tool.**

***Index Terms*—DSTATCOM, motor starting, power quality, voltage flicker.**

I. Introduction

Power quality has always been a concern and problem in the distribution system. One of these problems, voltage flicker, is especially frustrating because it can cause a process to stop, individual components to mis-operate and result in customer complaints to the utility providing the service. Voltage flicker is primarily caused by a sudden increase in load on a weak power system. The load increase causes the supply voltage to drop and, among other things, the lights to dim or flicker. An extreme example of a sudden load increase is the starting of a motor. During starting, a motor will draw up to eight times full load current. As the motor accelerates, the current drawn decrease to the level needed to match the mechanical load, usually less than the full load current. A new tool available to power system engineers is the DSTATCOM. Presently, few are installed and they are applied to mitigate voltage flicker due to sudden loading.

II. Case Study Facility

To assess the ability of a DSTATCOM to assist with voltage flicker problems during motor starting, an existing facility was modeled. A mine located in a relatively remote location was chosen. The mine load is approximately 5 MVA and the utility connection is at 25 kV through a 20 mile line. The other customers on this radial feed are a few ranches and a small village. At the main outdoor substation, a 25 kV to 4160 volt transformer feeds a 4160 volt bus. This bus has one feeder to the underground mining operation and one to the mill operation for processing of the raw ore. The loads consist of:

One (1)	800 HP synchronous mill motor
One (1)	300 HP air compressor for the mill operation
Eighteen (18)	30-200 HP motors for the mill operation
Nineteen (19)	50-250 HP motors for the underground mine

This exemplifies a typical voltage flicker problem. Before the large mill motor can be started, many or all of the smaller motors in the mill operation must be running. In addition, the motors for the underground mining operation must remain running as it is very inconvenient, cost-prohibitive and unsafe to stop the underground mining operation to start the mill motor. This results in the mill motor starting in the most difficult situation; all other motors running.

Motor starting simulations were performed using a commercially available power system study software package. As a point of reference, motor starting simulations were performed using a direct motor start and no corrective action. This resulted in a voltage drop to 50% of nominal and the mill motor did not successfully start. In a practical application, the electric coil used to close a motor contactor would release above this point. To account for this, a simulation was prepared where the loads from any bus are removed if their bus voltage drops below 65% of nominal. During this simulation, the mill motor is able to start as many of the smaller mill and mine motors are removed from the system when their voltage drops below the trip value. This provides additional system capacity for the mill motor during start. Unfortunately, the mill motor is now running with many of the supporting motors stopped. Clearly, this is not acceptable.

A. Auto-transformer Start

A traditional solution to this problem is applying an auto-transformer starting package. Connecting an auto-transformer in series with the motor will allow the application of a reduced starting voltage. With a motor being a constant impedance load during start, reducing the voltage will reduce the starting current. Additionally, the reduced voltage will prevent the motor from obtaining full speed. After a determined time delay, full voltage is applied to the motor and it accelerates to full speed. This method has been applied for many years, requires minimal maintenance and has a high

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reliability. The approximate cost for an auto-transformer starting package for an 800 HP, 4160 volt motor is $50,000.

Simulation of this method was performed using several auto-transformer tap values, with the tap of 65% resulting in the lowest voltage drop. The simulations showed that all motors would remain running following the start of the mill motor. However, as shown in Figure 1,the voltage dropped to approximately 68% of nominal, very close to the value where motor contactors may release. Also, the addition of any load within the mine or on this distribution feeder may eliminate this option completely and a voltage drop of this magnitude would probably result in complaints to the utility by other customers in the area. While it solves the problem from the facility perspective, the voltage drop is large enough that this cannot be considered a solution.

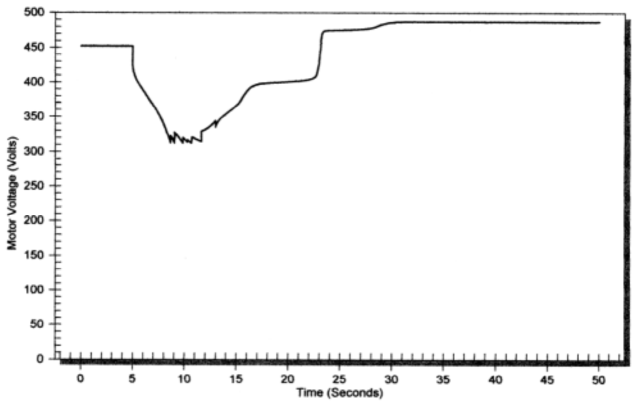

Figure 1. 480 Volt Bus Voltage in Mill During Auto-transformer Start

B. Solid State Soft Start

The decreasing cost of medium voltage solid state switching components has greatly increased the use of solid state soft starts for voltage flicker mitigation during motor starting. They are a reliable, low-maintenance, low-cost option that have replaced the auto-transformer package as the reduced voltage starting method. A Silicon Controlled Rectifier (SCR) initially turns on very close to the next zero-crossing of the source signal, resulting in a low output voltage. The SCR is gradually initiated earlier in the cycle, increasing the output voltage until full output voltage is obtained, at which time the SCR bank is bypassed by a conventional contactor. The estimated cost of a solid state soft start package for the mill motor is $30,000.

Simulations were run and the best performance was found when starting with 10% of nominal voltage and ramping to 70% of nominal over 8 seconds. This resulted in a voltage drop to approximately 70% of nominal. While this allows the facility to continue operation, the voltage drop is close to that where the electric coil of the motor contactors may release. For many of the reasons listed above, this can not be considered a solution.

C. Additional Onsite Generation

The original facility design included a 1750 kW diesel generator for paralleling with the utility to assist with the across-the-line starting. Simulation of this scenario showed a voltage drop to approximately 92% of the nominal voltage, as shown in Figure 2. This allows the facility to continue operation.

Unfortunately, a standby diesel generator requires much more maintenance and has a much higher failure rate than other electrical components. The IEEE Std 493 (Gold Book) lists many reference papers regarding electrical equipment reliability. Table I summarizes the failures per unit year of several common pieces of equipment found at this facility [1].

TABLE I
FAILURE RATES OF COMMON ELECTRICAL EQUIPMENT

ELECTRICAL EQUIPMENT	FAILURES PER UNIT YEAR
Motor Starters (601 to 15000 V)	0.0153
Synchronous Motors (601-15000 V)	0.0318
Transformers, Dry-type	0.0036
Circuit Breakers (Above 600 V)	0.0036
Standby Diesel Generators	5.3

The approximate cost of a generator this size is $350,000. While the voltage drop is greatly reduced, the failure rate is a concern and resulted in the facility searching for another solution.

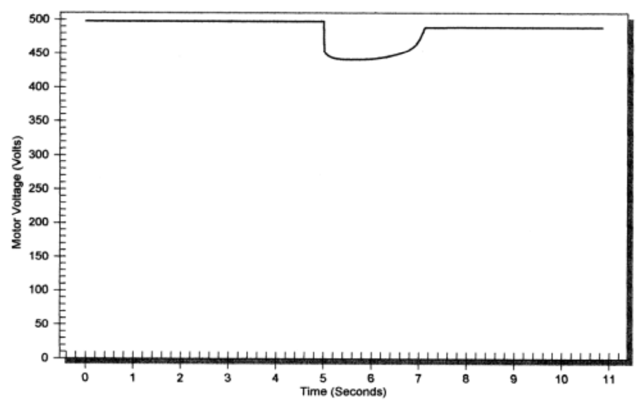

Figure 2. 480 Volt Bus Voltage in Mill During Direct Start with Onsite Generator

D. Improved Utility Source

This solution is usually used only as a last resort. Often it involves the addition of a new utility substation or the relocation of an existing substation closer to the facility. Typically, the design and construction would be performed by the utility and the cost covered by the user or users requiring the improved source.

The nominal cost for this solution is $500,000 to $1,000,000. Also, it may take some time to complete as equipment must be purchased, environmental studies must be performed and several levels of public approval are needed.

It is interesting to note that this option was chosen by the facility, as the reliability of the on-site generator became an issue. With this improved utility source, the voltage drops to approximately 88% of nominal during a direct start of the mill motor.

E. Evaluation of Traditional Solutions

As the data shows, several options are available with a wide degree of performance. The soft-start has the lowest cost, but does not minimize the voltage drop to an acceptable level. The best performance is provided by the addition of on-site generation, although this has problems associated with reliability. The only other alternative that will solve the problem is to improve the utility source. While this has a much higher reliability, it comes with a significantly higher price. Clearly, there is a need for a solution with a high level of performance, high reliability and low cost.

III. Application of a DSTATCOM

Improvements in medium voltage solid state switching technology have led to a new tool for power system problem solving. The DSTATCOM has been used to solve voltage flicker problems in other situations. In both a saw mill and a rock crushing facility, the voltage flicker problem was the result of the sudden loading of the motors due to the process. That is, cutting of a log would begin, or a rock would enter the crusher. This case study is unique in that the flicker problem occurs during the starting of the motor and is significant enough to cause many of the smaller supporting motors to stop.

The computer simulations completed to evaluate the application of the DSTATCOM were performed using a commercially available EMTP-based software package [2].

A. Facility Model

The facility model was verified by comparing the results of the load flow study completed with the power system study software to those of the EMTP-based software. The torque requirements of each motor was adjusted to match bus voltages and feeder currents. Following that, a direct start with no corrective action was simulated. As with the power system study software, the bus voltages dropped to approximately 50% of nominal

B. Modeling of the DSTATCOM

A computer model of the DSTATCOM was created in the EMTP-based software. Specific component details for the 2 MVAR unit were provided by the manufacturer and are listed below [3] [4].

TABLE II
DSTATCOM Component Details

Component	Value
Energy Storage Capacitor	600 µF
Inverter Method	Carrier Comparison
Carrier Modulation Frequency	3060 Hz
Inverter Output Voltage	2520 V_{L-L}
AC Filtering Capacitor	200 kVAR
Output Transformer Size	2.2 MVA

The DSTATCOM was connected to the facility 4160 volt bus with a simulated load to verify operation. The control parameters were adjusted to improve the response to load addition. Once the optimal settings were found, the simulated load was removed and the model of the mine was connected.

C. Application of DSTATCOM

With the DSTATCOM connected to the 4160 volt bus, the mill motor was direct started. The voltage dropped to approximately 92% of nominal, as shown in Figure 3. This is a significant improvement over operation without correction. Additionally, information provided by the manufacturer places the unit availability between 95% and 99%.

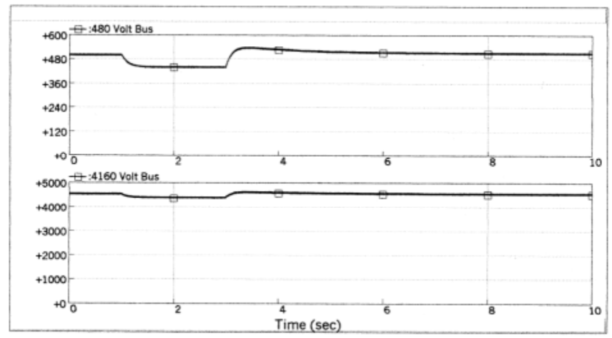

Figure 3. 480 and 4160 Volt Bus Voltages in Mill During Direct Start with DSTATCOM

IV. Evaluation of Alternatives

Several alternatives are available to solve this problem, each has strengths and weaknesses.

The auto-transformer start and solid state soft start packages reduce the voltage flicker during the motor start; however, the voltage drop is still too large. The use of an onsite generator reduces the voltage flicker to an acceptable level but has reliability issues that impact operation of the mill process, thus revenue of the facility. Improving the utility source also reduces the voltage flicker to an acceptable level with acceptable reliability but a significantly higher cost.

The DSTATCOM reduces the voltage flicker to an acceptable level, has an acceptable level of reliability and is expected to have a reasonable cost.

TABLE III
Evaluation of Alternatives

Alternative	Approximate Cost	% Nominal Voltage During Start	Reliability
Auto-transformer	\$50,000	68 %	High
Solid State Soft Start	\$30,000	70 %	High
Onsite Generation	\$350,000	92 %	Low
Improved Utility Source	\$500,000 to \$1,000,000	88 %	High
DSTATCOM		92 %	High

V. CONCLUSIONS

From a performance perspective, the addition of onsite generation, an improved utility source and the addition of the DSTATCOM are possible solutions. The only solutions with the required level of reliability are an improved utility source and the addition of the DSTATCOM. Since the cost of a DSTATCOM is expected to be comparable to the addition of onsite generation, it is the only solution that meets all of the requirements.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

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VIII. BIOGRAPHIES

Kent Choma received the BSEE in 1990 from the University of Alberta, Canada, and MSEE in 2001 from the University of Nevada Reno. Work experience includes field service, utility and consulting organizations. Presently he is a Supervising Engineer for Electro-Test, Inc. and is completing graduate studies at the University of Nevada Reno. Interest include power system protection, dispersed generation and electrical equipment failures. Kent is a Registered Professional Engineer in the states of Nevada and California.

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