# Closure to Discussion of "Active Voltage Correction for Industrial Plants"

Robert A. Hanna, David Ezer, and John Penny

The above paper [1] introduces the active voltage conditioner (AVC) as a modern high-power high-performance inverter-based voltage conditioning solution. It provides fast, accurate voltage sag correction as well as continuous voltage regulation. The responsiveness and continuous control of this new inverter technology far exceeds that of the traditional transformer-based ac voltage regulator solutions, and the cost effectiveness and affordability overcome the high acquisition and operational costs barriers that preclude uninterruptible power supplies from being applied broadly to noncritical applications.

The AVC employs a phase-locked loop in its control circuit that phase synchronizes an internally generated reference voltage to the pre-sag fundamental component of the incoming supply voltage. The magnitude of the internal reference voltage is defined by the desired nominal value. The correction voltage produced restores the output voltage to this internal reference voltage level correcting sags, transient phase shifts, and undervoltages up to the limit of its correction capability. In this way, phase jumps associated with voltage sags and continuous unbalance associated with unbalanced phase loading are corrected. In addition, harmonic voltages can be removed from the supply and flicker voltages attenuated by the AVC.

We agree with Dr. Barros that peak voltage waveform flattening caused by harmonic voltage distortion in the supply reduces the ability of a large range of electronic equipment to ride through voltage sags. Harmonic voltage distortion of this type is common in the industrial environment and is typically caused by three-phase bridge rectifiers in ac motor drives. The AVC has the ability to remove this harmonic voltage distortion, as shown in Fig. 1, and restore the peak sine wave of the voltage waveform at the AVC output. This improves the resilience of the connected electronic equipment to voltage sags. Importantly, this is as a consequence of the AVC providing continuous correction and cannot be achieved by offline products.

Fig. 2 shows the response of the AVC to a voltage sag to 70% for 100 ms. Such a sag could be caused by a fault on the local distribution network, and would often cause electronic equipment to trip or shut down. The AVC restores the output voltage to nominal in just over half a cycle. Sensitive electronic equipment would be completely protected from the voltage sag and continue operating without interruption.

The correction ratio in the standard AVC has been chosen to optimize its value to the customer based on a statistical analysis of commonly occurring voltage sags, a knowledge of the typical equipment susceptibility levels, and the cost of power electronic components. Power quality monitoring has shown that outages, micro-cuts, and even very deep voltage sags are statistically less common than voltage sags in the power network. Far more common are more shallow short-duration voltage sags which can be just as disruptive. A sag to 70% remaining voltage is often enough to cause forced equipment interruptions or malfunction, resulting in costly production loss. Voltage correction products containing energy storage and providing correction of outages for a very short duration are often underutilized and represent a reduced net worth to the customer compared to an optimally rated product such as the AVC whose correction ability is more fully utilized.

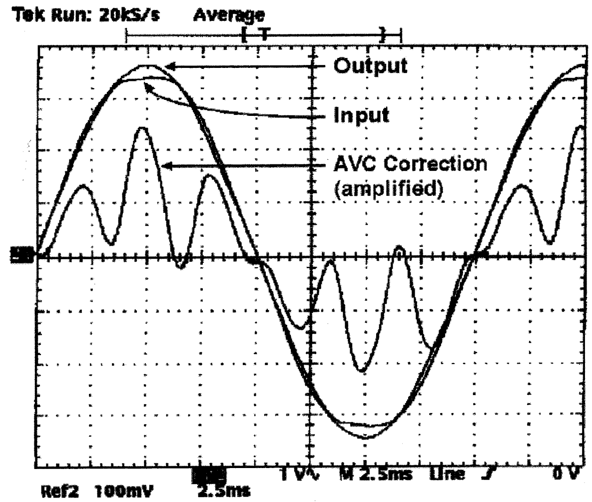


Fig. 1. AVC regulation of "flat-topped" supply voltage waveform (input). The AVC correction voltage is amplified for clarity.

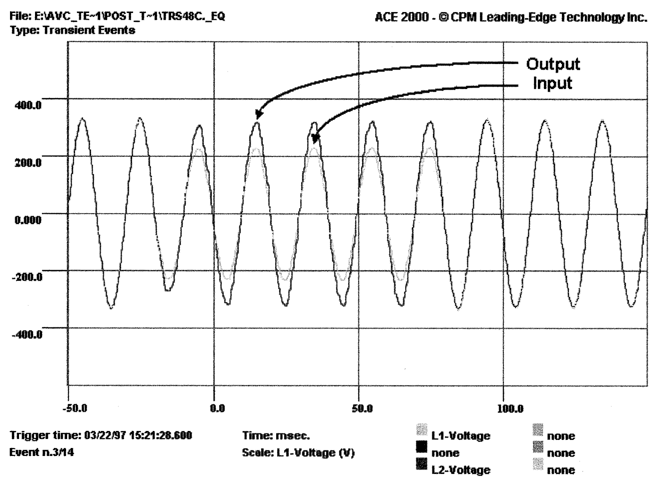


Fig. 2. AVC response to a voltage sag.

The AVC's primary role is to mitigate problems associated with voltage sags. It does not provide protection against momentary or prolonged loss of power events which are much less common. The AVC contains no battery energy storage and draws its power from the ac supply. Therefore, the maintenance and operational costs, safety and environmental hazards, and operating temperature constraints of large battery banks are eliminated. The size of the unit is reduced so it occupies less valuable factory space and lends itself to be retrofit into space-confined switch-rooms. The largest AVC in service today is 1.6 MVA, supplied to a manufacturer of solar cells in the U.S. who was experiencing significant problems with silicon cutting saws during utility induced voltage sags. These had resulted in high costs due to plant downtime, repairs, wasted product, and startup costs. The AVC has protected the plant from the majority of these events since its installation in October 2002.

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R. A. Hanna is with RPM Engineering Ltd., Mississauga, ON L5K 2R1, Canada (e-mail: r.hanna@ieee.org).

D. Ezer is with Linco Power Ltd., Toronto, ON M3J 2W6, Canada (e-mail: david@lincpower.com).

J. Penny is with Vectek Electronics Ltd., Napier HB 4001, New Zealand (e-mail: john@vectek.co.nz).

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The AVC is now available for indoor and outdoor installations. Units as large as 10 MVA and up to 36-kV class can be provided.

AVCs with nonstandard correction ratios can also be produced for different applications, such as when regulation is more important than sag correction in a test facility, or when a specific harmonic voltage problem needs to be addressed. In addition, the AVC provides continuous regulation of the supply voltage, allowing the process to be improved or optimized.

Ideally, a voltage sag coordination chart matching the sag characteristics of the distribution system with the voltage tolerance levels of the equipment would be used to select an appropriate voltage protection scheme. However, this requires localized voltage disturbance monitoring and/or sag testing of equipment. In some cases, this is performed, however, because of the time taken to perform voltage monitoring, availability and transportability of sag generators, and additional costs involved, in many other cases this is reluctantly pursued by the customer or consultant. Installing a small-rated AVC on selected susceptible equipment, possibly alongside voltage monitoring, is one way of proving its viability to the customer at a relatively reduced cost.

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## REFERENCES

[1] D. Ezer, R. A. Hanna, and J. Penny, "Active voltage correction for industrial plants," *IEEE Trans. Ind. Applicat.*, vol. 38, pp. 1641–1646, Nov./Dec. 2002.