

AdaptiVolt™ Based CVR in Industrial Applications
Technical Synopsis

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Background

This Technical Synopsis provides engineers and other interested parties with background information and appropriate references on various industrial electrical production equipment and components' reaction to Conservation Voltage Regulation (CVR) using AdaptiVolt™. It focuses on electric production and operational support equipment in a typical Pacific Northwest paper mill. A paper mill was selected for discussion because it uses many of the same processes used in other industrial facilities as well as being one of the major industrial users of electrical energy in the Pacific Northwest. Information is provided on how individual electrical devices such as transformers, motors, variable speed drives, ballasted lights and other equipment will react to AdaptiVolt™ based CVR. Reactions are individually described and referenced.

Discussion Specific to CVR in Paper Mills

In an earlier study commissioned by Bonneville Power Administration (BPA), an assessment was made on the potential conservation available using CVR at industrial facilities¹, including paper mills in the Pacific Northwest. Table 1 shows the types of loads, the approximate distribution of end use loads and the savings expected with a 2.5% voltage reduction.²

Types of Paper Mill End Use Loads	Average Mw (AMw)	% of Total AMw	Estimated AMw Savings	% of Total Savings	% Savings	CVRf
Pump, Fan and Compressor Motors	410	34%	3.9	46%	0.95%	0.38
Motors used for Materials Processing	370	30%	0.8	10%	0.22%	0.09
Motors used for Materials Handling	330	27%	3.4	40%	1.03%	0.41
Other End uses	110	9%	0.3	4%	0.27%	0.11
Totals	1220	100%	8.4	100%	0.69%	0.28

Based on data in Figures 5.4 and 5.5 in J.G. De Steese, S.B. Merrick, R.C. Tepel and J.W. Callaway, Assessment of Conservation Voltage Reduction Applicable on the BPA Service Area, Richland: Pacific Northwest Laboratory, 1987

Table 1

The study did not include any process heat energy savings nor did it include any non-motor loads.³ It is important to note that in the BPA study, only end-use loads were considered to provide savings.⁴ It did not include potential savings from the power distribution system and transformers in the facilities, even though transformers show significant loss reduction when

¹ J.G. De Steese, S.B. Merrick, R.C. Tepel and J.W. Callaway, *Assessment of Conservation Voltage Reduction Applicable on the BPA Service Area*, Richland: Pacific Northwest Laboratory, 1987.

² De Steese, Merrick, Tepel and Callaway 5.13. (The data was estimated from the bar graphs shown.)

³ De Steese, Merrick, Tepel and Callaway 5.12.

⁴ De Steese, Merrick, Tepel and Callaway 5.10.

operating at reduced voltages.⁵ Also, the original load data was taken from utility revenue metering data, the only available data at the time.⁶

Since the time of the study in 1987, paper mill loads have changed. VSDs have been added to pumps, fans, compressors and material handling motors. New electronic drive systems have been added to paper machines and other paper processing equipment. Additionally, the use of computers and digital microprocessor-based control systems has grown. New power system control technology and measurement, digital metering, and evaluation techniques are available to better measure and control energy use, energy conservation and demand.

Later studies^{7,8}, actual experience and data collected by PCS UtiliData⁹ have shown that the original CVR-based conservation estimates were extremely conservative. Actual CVR-based conservation results have been higher than early estimates predicted.

Individual Electric Equipment CVR Reaction

The following list outlines individual electric components reaction to CVR using an automated energy conservation system.

1. Transformers

- a. The primary mechanism of power reduction, energy conservation and power factor reduction when applying CVR to transformers is the reduction in no-load or core losses. There are two components of core loss:
 - i. Eddy Current Loss, $P_e = K_e f^2 B_m^2$ where K_e is a constant that depends on core resistivity and lamination thickness, f is the frequency and B_m is the magnetic flux density.¹⁰
 - ii. Hysteresis Loss, $P_h = K_h f B_m^n$ where K_h is a constant and n both depends on the core material (n is often assumed to be 1.6¹¹).
 - iii. Magnetic Flux Density, $B_m = k(V/f)$ where k is a constant, V is the voltage and f is the frequency.¹²
- b. Operating transformers over rated voltage significantly increases losses and also reduces the transformer power factor. Conversely, reducing transformer voltage reduces losses and improves power factor.

⁵ M.S. Chen, R.R. Shoults and J. Fitzer, *Effects of Reduced Voltage on the Operation and Efficiency of Electric Loads, Volume 1*, EPRI, Arlington: University of Texas, 1981, 3.155.

⁶ De Steese, Merrick, Tepel and Callaway, 5.10.

⁷ J.G. De Steese, S.B. Merrick and B.W. Kennedy, "Estimating Methodology for a Large Regional Application of Conservation Voltage Reduction," *IEEE Transactions on Power Systems*, vol. 5, no. 3, Aug. 1990, pp. 862-870.

⁸ B.W. Kennedy and R.H. Fletcher, "Conservation Voltage Reduction (CVR) at Snohomish County PUD," *IEEE Transactions on Power Systems*, vol. 6, no. 3, Aug. 1991, pp. 986-998.

⁹ T.L. Wilson and D.G. Bell, "Energy Conservation and Demand Control Using Distribution Automation Technologies," Will be presented at IEEE 2004 Rural Electric Power Conference, Scottsdale, AZ, 2004.

¹⁰ Ralph J. Smith, *Circuits, Devices and Systems A First Course in Electrical Engineering*, (New York: John Wiley and Sons, 1966) 518.

¹¹ Smith 517.

¹² Smith 518.

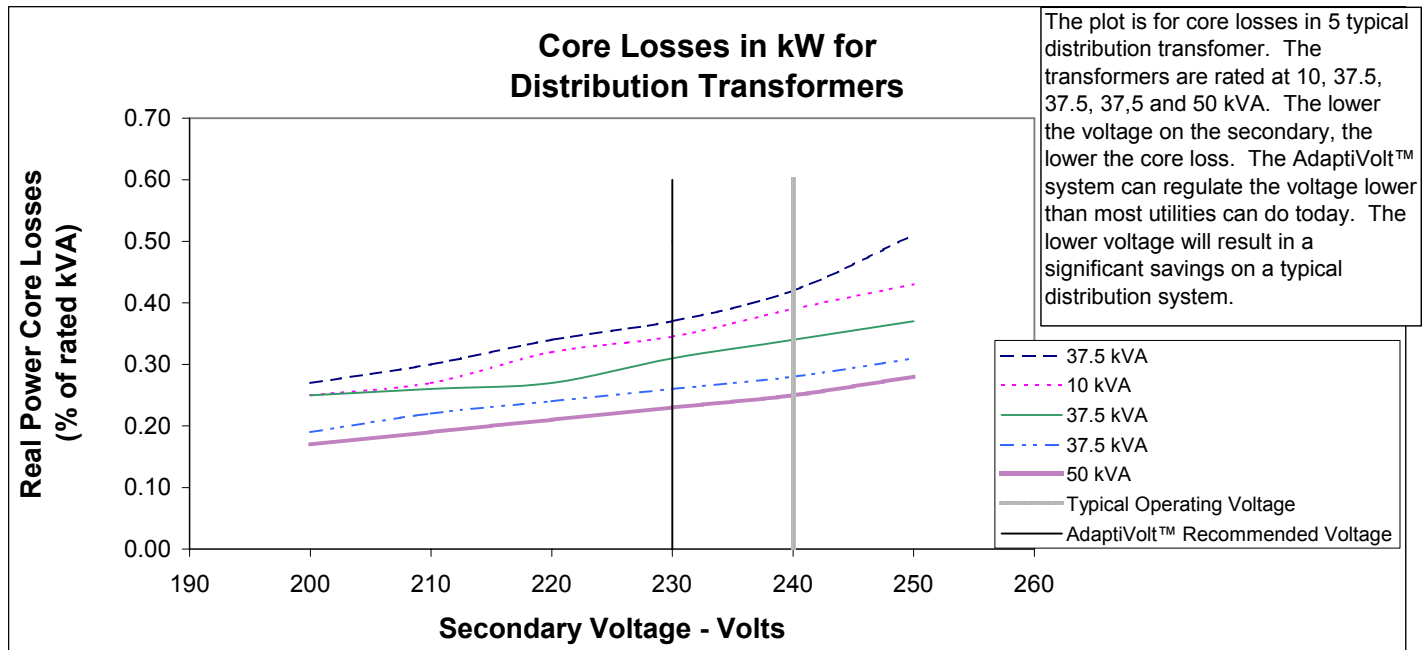


Figure 1¹³

- c. The resultant CVR reduction in end-use load will reduce the load that the transformer must carry and therefore will reduce the load loss component of transformer loss.
- d. Transformers are found throughout the power system and, frequently, in end-use devices, especially electronic power supplies, televisions, distributed process control systems, programmable logic controllers, and computers.

2. Electronic Power Supplies

- a. The primary mechanism of power reduction and energy conservation with CVR in any type of electronic power supply is the reduction in switching losses at the semiconductor junction. As long as the voltage is sufficient to provide the load, the efficiency of the supply will increase until the voltage is no longer sufficient to supply the load. The ANSI allowable voltages are much higher than the acceptable lowest usable voltages from an energy efficiency perspective. Most power supplies are sized conservatively to supply the load, thus making them excellent candidates for energy conservation using CVR. Charts showing the efficiency of electronic power supplies are available from most manufacturers and can be found on the Internet.
- b. Many electronic power supplies have transformers and reactors that react to CVR as discussed above.

3. Lighting

- a. *Incandescent* – The mechanism of power and energy reduction with CVR for incandescent lighting load is one of the easiest to understand. Simplistically, the power reduced is proportional to the difference of the squares of the voltages before and after the voltage reduction. The light output will be also be reduced, but as long as voltages are within ANSI allowable levels the loss in light output is usually not noticeable. The life of incandescent lamps is increased markedly by operating at the

¹³ Chen, Shoultz and Fitzer 3-154, Figure 3-214

lower allowable voltage range and decreased by as much as 50% for 5 percent over rated voltage.¹⁴

- b. *Fluorescent* - Voltages over nameplate tend to push the magnetic portion of the ballast to saturation.¹⁵
 - i. Magnetic Ballast – The energy conservation from CVR is the same as the conservation from transformers. Testing on some magnetic ballast fluorescent lamps indicates the performance index of the lamp improves as the voltage is reduced.¹⁶
 - ii. Electronic Ballast - The energy conservation from CVR is the same as the conservation from electronic power supplies.

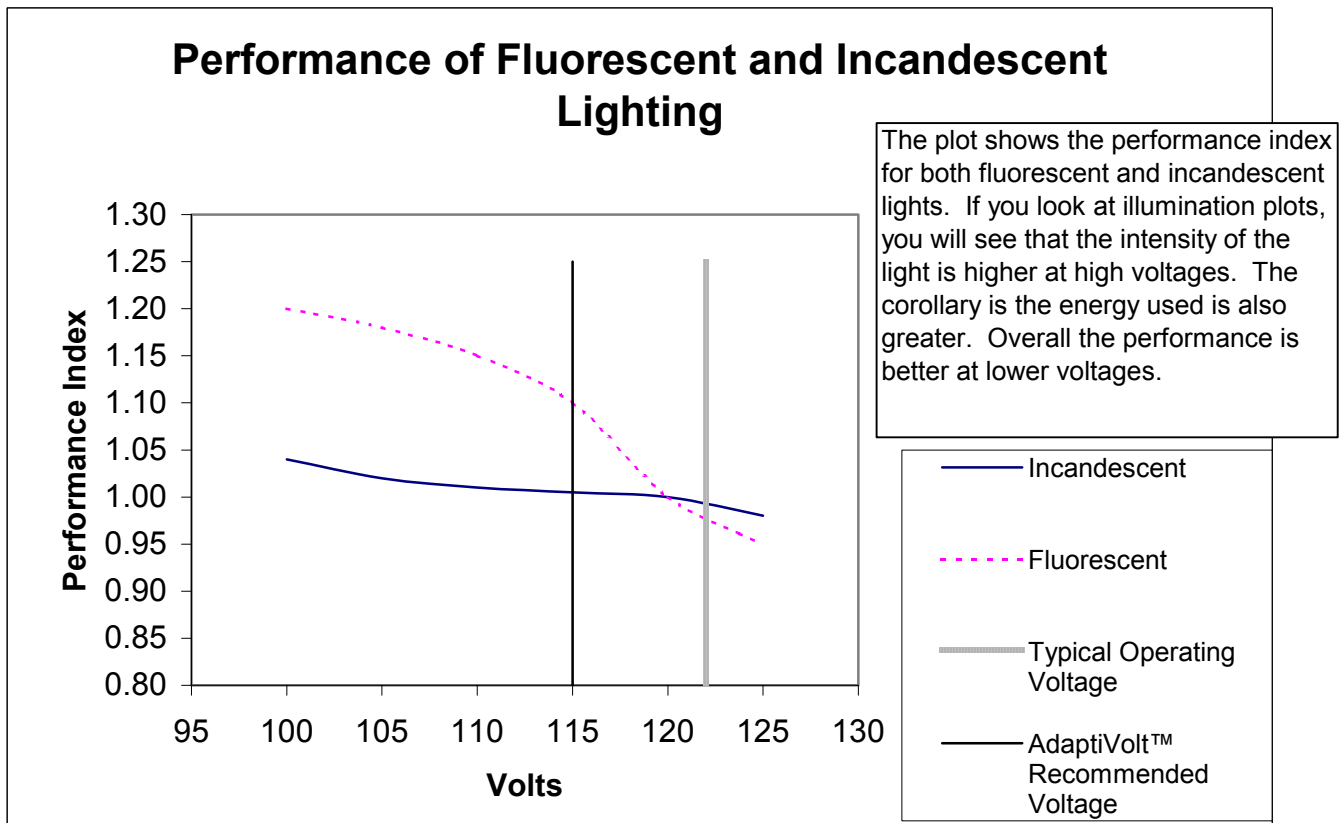


Figure 2¹⁷

- c. *HID* – Depending upon the type of ballast, the savings will occur from either the same mechanism as transformers or from electronic power supplies.
4. AC Motors – The majority of energy savings obtained using automated CVR at an industrial facility will come from AC motors. The energy conservation available from AC motors with CVR depends on the application, the motor type, size, design, and load, and on the speed, load, and torque characteristic of the driven load.

¹⁴ E. Cowern. Electric Motors and Voltage. The Cowern Papers. [Online]. Available: <http://motorsanddrives.com/cowern/motorterms12.html>

¹⁵ Cowern.

¹⁶ Chen, Shoults and Fitzer 3.157.

¹⁷ Chen, Shoults and Fitzer 3-157 & 158, Figure 3-216 & 217.

- a. In general, if a motor is operating with full mechanical load, then it is most efficient at full nameplate voltage and less efficient at voltages over or under nameplate voltage. At loads under rated load, efficiency increases as voltage is reduced. When operating over rated load, the efficiency does improve. However, this overload situation can not be operated for extended periods of time. In all cases the reactive power input to a motor decreases as the voltage is reduced.¹⁸ Power factor improves with lower voltage and drops sharply with high voltage.

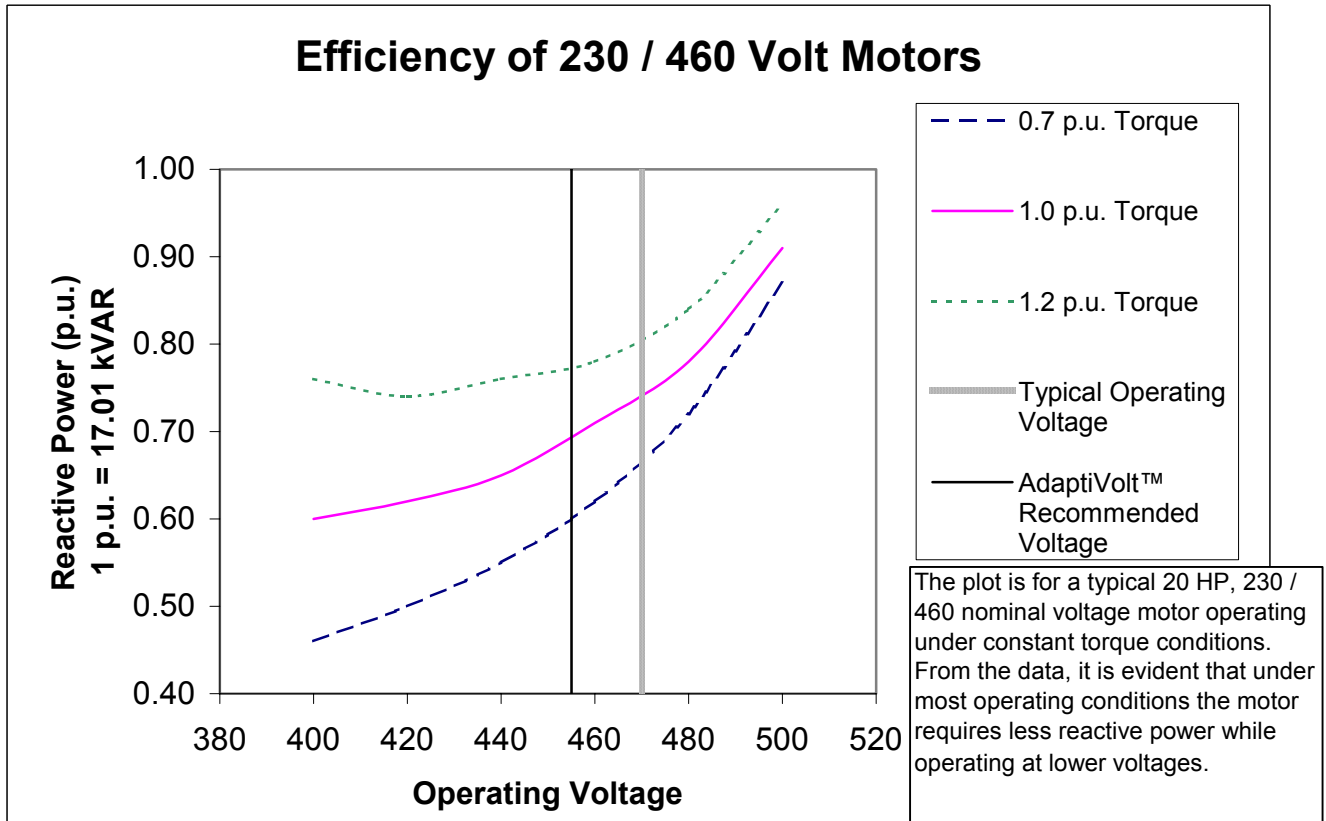


Figure 3¹⁹

¹⁸ Chen, Shoults and Fitzer 3.101 through 3.152.

¹⁹ Chen, Shoults and Fitzer 3-149, Figure 3-210.

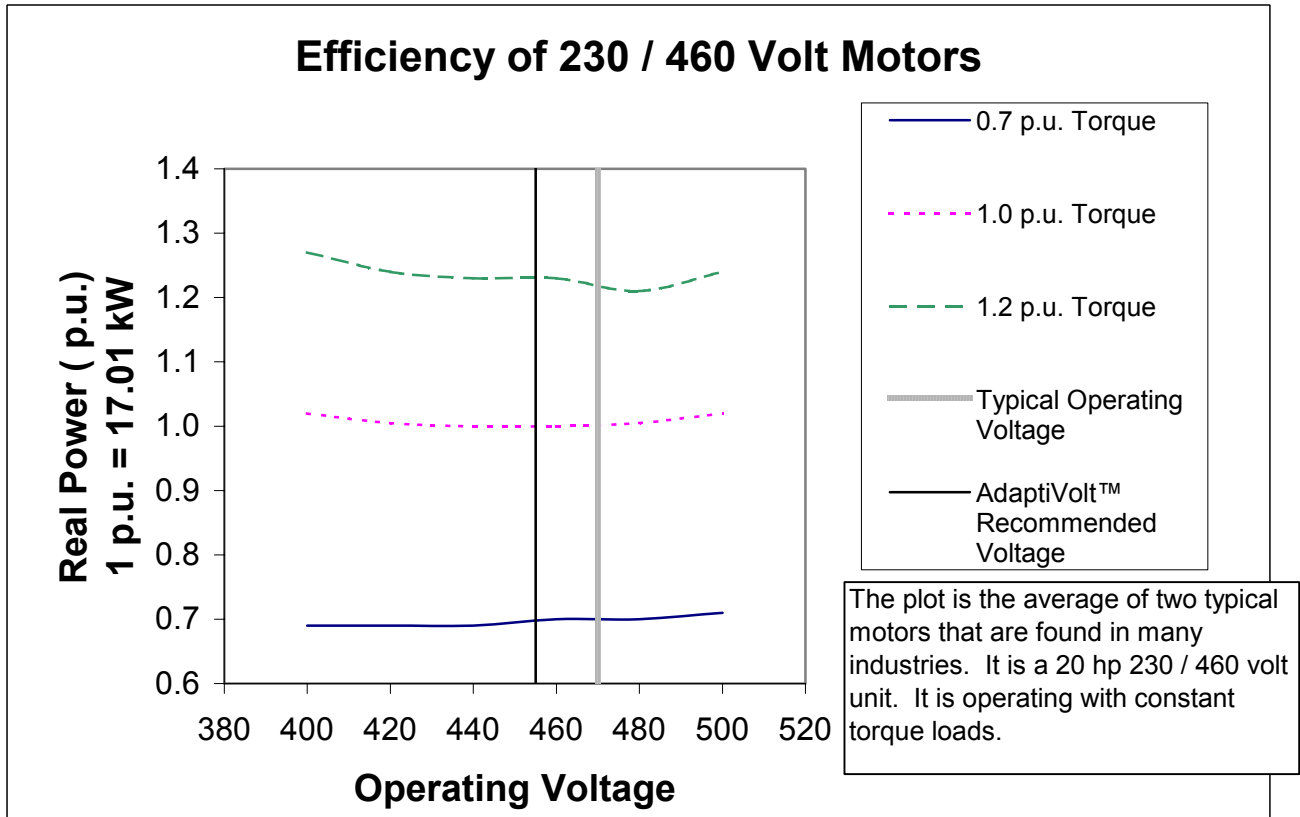


Figure 4²⁰

- b. If a motor is operating at less than full load, reducing terminal voltage will reduce losses and improve efficiency. This technique is used by many VSDs to improve energy efficiency.²¹
- c. For motors where the speed is not feedback controlled, reducing the terminal voltage will reduce the output torque. The slip will increase and the speed will decrease. In applications such as man cooler fans or ventilation fans, the load will reduce as a function of the cube of the speed thereby further reducing energy usage.
- d. In general, the percentage efficiency improvement for small motors is much greater than for large motors.²² High efficiency motors will not show as much improvement as the standard motors.²³
- e. For motors that are being operated by VSDs, the energy savings attainable with automated CVR will be those saved in the isolation transformer and in potential switching loss reduction as in electronic power supplies.

5. DC Motor Systems

²⁰ Chen, Shoultz and Fitzer 3-143, Figures 202 & 203; & 3-148, Figure+A21s 3-208 and 3-209

²¹ H.A. Rashidi, A. Gastli, and A. Al-Badi. (2001). Optimization of Variable Speed Induction Motor Efficiency Using Artificial Neural Networks. *Proc. Australasian Universities Power Engineering Conference '01*. [Online]. pp. 298-303. Available: http://www.itee.uq.edu.au/~aupec/aupec01/035_Gastli_AUPEC01paper%20revised.pdf

²² Cowern.

²³ Cowern.

- a. For electronic drive systems, the energy savings attainable with CVR will be those saved in the isolation transformer and in potential switching loss reduction as in electronic power supplies.
 - b. For legacy motor generator set drive systems, the energy savings will be those saved in the motor generator set motors.
6. Process Loads
- a. In general, closed loop process loads will not be affected by CVR and no additional energy conservation will occur except that which occurs with reduced transformer losses, reduced electronic power supply losses, reduced lighting losses, and reduced motor losses.
7. Computers
- a. All computers have electronic power supplies and/or UPS systems supplying them. These will provide the energy conservation components as discussed above.

Power System and General Comments

High voltage tends to reduce power factor and increase system losses which results in higher operating costs for the equipment and the system. The reduced power factor is due primarily to the over-excitation of transformer, motors and other system magnetics. Operating automated CVR will tend to improve overall system power factor.

UtiliData® AdaptiVolt™ is not intended as a replacement for power quality equipment used to prevent surges, sags, transient over voltages, harmonic voltage distortion or flicker. However, the UtiliData® AdaptiVolt™ system data collection and power monitoring capabilities can provide extremely useful information on industrial plant power quality issues and can be used as a resource in evaluating the need for additional power quality measures.

Regarding the EPRI PQ Commentary²⁴

The generally negative EPRI PQ commentary was written in response to the year 2001 proposal in California to reduce distribution voltages to 10% below the nominal value rather than reducing it to the ANSI minimum level of 5% below the nominal value. The tone of the letter appears biased in that it starts out saying that CVR is “otherwise known as ‘brownout.’”

CVR is not ‘brownout,’ it is operation of equipment within nameplate ratings whereas ‘brownout’ implies operating at less than nameplate voltages. There is data available, some listed below, that provides answers to what happens when devices are operated within the lower range of their nameplate ratings. A key point to keep in mind is with AdaptiVolt™, **voltages will be prevented from going below acceptable minimum levels for efficient and effective operation.**

Conclusion

This Technical Synopsis provides numerous technical articles that characterize the reaction of individual electrical components to automated CVR. Because De Steese, Merrick, Tepel and Callaway only used motor loads for their energy conservation estimates (Table 1) and other loads can and will provide energy savings when operating under automated CVR, it can be reasonably expected that greater energy savings will be attained when operating UtiliData® AdaptiVolt™.

²⁴ EPRI. (2001 Dec). The Power Quality Implications of Conservation Voltage Reduction. *PQ Commentary*. [Online]. Available: http://www.e2i.org/e2i/docs/comm_41_final.pdf

Other References of Interest (Not included in footnotes)

1. W. Finley. Trouble Shooting Induction Motors. Siemens Energy and Automation, GA. [Online]. Available: <http://www.sea.siemens.com/motorsbu/product/White%20Papers/Troubleshooting%20Induction%20Motors.pdf>
2. D. Ezer, R.A. Hanna, J. Penny. (2002 Nov./Dec.). Active Voltage Correction for Industrial Plants. *IEEE Transactions on Industry Applications*. [Online]. 38(6), pp. 1641-1646. Available: <http://rpm-eng.com/publications/pubdec2002.pdf>
3. GE Industrial Systems. (2001 Apr.). AC Motor Selection and Application Guide. GE Industrial Systems, IN. [Online]. pp. 2-3. Available: <http://www-test.geindustrial.com/products/brochures/GET-6812D.pdf>
4. H.D. Laird, S.D. Round, R.M. Duke and A. Gardiner. (1998). Power Quality Observations at a Light Industrial Site. *Proc. Intl. Conf. on Harmonics and Quality of Power 1998*. [Online]. 1, pp. 88-93. Available: http://www.elec.canterbury.ac.nz/research/powerelectronics/publications/ICHQP1998_PQ.pdf
5. E. Cowern. (2001 May 1). The Highs and Lows of Motor Voltage. *EC&M*. [Online]. Available: http://www.ecmweb.com/ar/electric_highs_lows_motor/
6. D.W. Finn and M.J. Ouellette. (1992 Aug.). Compact Fluorescent Lamps: What You Should Know. *Progressive Architecture*. [Online]. pp. 89-92. Available: http://irc.nrc-cnrc.gc.ca/practice/lig3_E.html
7. Defense Supply Center Philadelphia. (1999). Ballast – General Information. *Energy Efficient Lighting Catalog*. [Online]. 6, pp. 150-152. Available: <http://www.dscp.dla.mil/gi/general/lightcat/FLBAL%20gen.pdf>
8. Pacific Gas & Electric Company. (1999 Jan.). Voltage Tolerance Boundary. PG&E, CA. [Online]. Available: http://www.pge.com/docs/pdfs/news/latest_topics/power_watch/power_quality_notes/voltage_tolerance.pdf
9. Copper Development Centre. Understanding High Efficiency Motors. Copper Development Centre, Singapore. [Online]. Available: <http://www.copper.org.sg/pdf/HEM-Chapter1.pdf>
10. D. Chapman. (2001 Nov.). Voltage Dips: Introduction. *Power Quality Application Guide*. [Online]. Available: http://www.cda.org.uk/megab2/elecapps/pub501/51_lo_R2.pdf
11. J.A. Diaz de Leon II and C.W. Taylor. (2002). Understanding and Solving Short-Term Voltage Stability Problems. [Online]. Available: http://www.transmission.bpa.gov/orgs/opi/Power_Stability/PwrElectPanelAmSC.pdf

12. Regional Technical Forum (RTF). (2004 Apr.). Automated CVR Protocol No. 1. PCS UtiliData, WA. [Online]. Available:
http://www.pcsutilidata.com/White%20Papers/Automated_CVR_Protocol_1.pdf