VOLTAGE OPTIMIZATION: BEYOND THE HYPE.

What's the real ROI of voltage optimization for industrial and commercial enterprises?

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EXECUTIVE SUMMARY

Utilities in the United States and elsewhere have experimented with schemes to optimize voltage – narrow, and lower, the range at which voltage is delivered to conserve energy, reduce carbon emissions and reduce customer costs. Unfortunately, there is little economic incentive for utilities to move at more than a glacial pace toward general implementation.

Absent a delivery-side solution from utilities, marketing-oriented firms have rushed to fill the vacuum with client-side or demand-side optimization devices that can be purchased and installed by end users. These firms claim their technologies can reduce electrical consumption 10% to 30%, or even more in specific instances. But these numbers must be viewed skeptically. Qualified studies conducted by U.S. utilities indicate that voltage optimization can reduce electrical usage, but only by 0.5% to 4% on average, and then only for commercial customers. While these savings are not insignificant, in most cases they are not

enough to justify investment in a demand-side solution based solely on the cost of electricity.

Generally not factored into the return on investment equation, however, are the additional benefits derived from demand-side voltage optimization based upon modern automatic voltage regulators (AVRs). AVRs, an established and proven technology, allow dynamic fine-tuning of output voltage, which can reduce energy usage, as well as correct for supply voltage unbalance, which can significantly impact equipment longevity. These two factors, combined with the very real cost of carbon, significantly alter the ROI equation.

Without resorting to exaggerated marketing claims, data suggests that demand-side voltage optimization via the latest generation of lower cost automatic voltage regulators may now offer a solid return on investment for many industrial and commercial enterprises.

SHOULD WE WAIT FOR THE UTILITIES TO GET SMART?

We are all looking forward to the 'smart' energy future, where electricity is generated by renewable resources, power is intelligently optimized, motors run at maximum efficiency and utilities cooperate with business owners and individuals to lower costs and 'spin the meter backward.'

Unfortunately, this rosy future isn't likely to materialize for a very long time, as utilities (and the energy companies that supply them) have little reason to rush toward an optimized future. A recent article at IEEE Smart Grid sums up the problem.

> *Since costs are born by distribution network operators and benefits (energy savings) accrue mainly for end-users, the utilities have little incentive to invest.*[1]

1 Warner, Kellogg and Ron Willoughby. April 2013. "Conservation Voltage Regulation: An Energy Efficiency Resource." IEEE.

In other words, there is no real economic advantage for utilities to optimize the voltage they deliver to their commercial customers. While studies conducted by major utilities show a possible savings of between 0.5% and 4%,[2] lower energy usage means lower revenue. Without incentives, simple economics leads to inertia. The reality is, production-side optimization is likely still decades away.

Ironically, and to add to the bad news, the move toward greater use of solar and wind is actually pushing utilities to "de-optimize" voltage.[3] While the move away from carbon-based (and fission-based) power generation may be laudable, grid managers are actually having a difficult time dealing with the variability inherent in weather-dependent power sources. To compensate, they tend to push voltage to the higher side of an allowed range to ensure the delivered voltage does not drop below a guaranteed minimum threshold.

BUT ISN'T VOLTAGE OPTIMIZATION ALL JUST HYPE?

Voltage optimization is a hot topic. With utilities slow to address the issue on the delivery side, private companies have stepped in with solutions that purport to optimize voltage on the demand side.

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2 Skov, Thor. June 2013. "Trending Toward Distributed Voltage Optimization: A Simple Solution Overlooked." Sourced 12/1/2014 at http://tdworld.com/test-monitor-amp-control/trending-toward-distributed-voltage-optimization-simple-solution-overlooked.

3 For more information see: Mengewein, Julia. July 30, 2014. "German Utilities Bail Out Electric Grid at Wind's Mercy." Bloomberg. Sourced 12/1/2014 at http://www.bloomberg.com/news/2014-07-24/german-utilities-bail-out-electric-grid-at-wind-s-mercy.html; Morris, Craig. August 2014. "German Grid More Stable in 2013." Energy Transition. Sourced 21/1/2014 at http://energytransition.de/2014/08/german-grid-more-stable-in-2013/; Warner, 2013. Also see UST. "Europe's 'Green Grid' Driving Demand for Voltage Optimization Solutions. Sourced 12/1/2015 at http://www.ustpower.com/europes-green-grid-driving-demand-for-voltage-optimization-solutions/.

If the Internet is to be believed, equipment exists that can cut electrical usage by 10% to 30%, or more, through voltage optimization. These often "mysteriously engineered" products are heavily marketed, particularly in the UK, where the nominal range for voltage was lowered in 1995. The new target of 230V +/- 10% was set to harmonize the UK and EU grids. But there remained many areas in the UK where the phase voltage exceeded 240V.[4] This opened up opportunities for private companies to offer machinery designed to patch the national grid. The savings claims promoted in case studies published by these companies are likely quite geographically specific.

Outside the UK, the claims by voltage optimization vendors have generated considerable pushback. Critics go so far as to label optimization vendors, "snake oil salesmen,"[5] pointing out that voltage optimization often has little impact on actual energy consumption. Toasters, heaters and refrigerators working on reduced voltage simply draw more current or work for longer periods of time to compensate. Computer equipment generally consumes the same amount of power regardless of input voltage. And while the power consumed by older tungsten filament light bulbs and fluorescent lighting can be reduced through voltage optimization, LEDs and new florescent lights are typically voltage independent.

But while critics are probably correct relative to most domestic single-phase electrical applications, a more compelling case can be made for voltage optimization in three-phase industrial and commercial instances.

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4 The Carbon Trust. June, 2011. "Voltage Management: An Introduction to Technology and Techniques."

5 See discussion archived at http://cr4.globalspec.com/thread/66658/Voltage-Optimisation.

OPTIMIZATION VIA AUTOMATIC VOLTAGE REGULATORS

Automatic voltage regulators (AVRs), sometimes referred to as electronic voltage regulators, are a proven technology originally developed to ensure steady regulated voltage to the load regardless of the voltage received from a utility. AVRs are commonly deployed in regions of the world where the grid is suboptimal, where voltage is highly variable and where customers are subject to periodic brownout conditions. They are also deployed in urban areas where voltage often drifts upward past a point that triggers emergency power backup systems at data centers and other critical facilities. This occurs frequently in summer months, shortening the lifespan of expensive UPS system batteries and reducing overall system reliability.

AVRs electronically regulate voltage to a pre-determined target output voltage. This target output voltage can be adjusted up or down relative to specific site conditions. Newer units offer real-time intelligence. They continuously monitor the load, adjust to optimum voltage on the fly and can regulate output to +/- 1%, maximizing electrical economy without compromising performance of a given load. AVRs also correct three-phase supply voltage unbalance,[6] which can have a significant impact on motor life.

These factors alone are often enough to justify investment in an AVR for many industrial and commercial enterprises. Additional benefits, including carbon credits, reduced air conditioning costs, the opportunity for “peak shaving,” and the general electrical protection AVRs offer, make the case even more compelling.

6 Skov. June 2013.

THE COST OF CARBON

Industrial and commercial enterprises are under increasing government, shareholder and customer pressure to reduce the amount of carbon dioxide and other greenhouse gasses their energy usage generates. Carbon credit, or carbon offset markets, which quantify the cost of carbon units and create mechanisms to redeem or trade these units based on their market value, are developing globally under both compliance schemes and voluntary programs.

The EU has implemented a compulsory 'cap and trade' system, wherein carbon-producing commercial enterprises can buy and trade 'allowances.'[7] In the U.S., carbon trading toward the goal of overall greenhouse gas emission reduction is voluntary. While the value of a carbon unit is greater under compliance schemes, there is real value to be extracted in the rapidly maturing voluntary market as well. General Motors made the news in late 2014 when it announced it would purchase carbon credits from North Dakota grasslands.

While the cost of carbon currently plays only a modest role in the voltage optimization equation, its value is likely to grow over the next decade.

QUANTIFYING THE VALUE OF VOLTAGE OPTIMIZATION

Justifying investment in a voltage optimization program via installation of demand-side automatic voltage regulators remains dependent upon several significant variables, including the local cost of electricity, the percentage of electrical load that is voltage dependent and, to a lesser degree, the local value of carbon credits.

We do know, however, that utility power can almost always be optimized and that older lighting and many motor-driven processes are voltage dependent.

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7 See http://ec.europa.eu/clima/policies/ets/index_en.htm

Combining data on the factors listed below allows us to calculate the “hype free” benefits of voltage optimization via automatic voltage regulation.

- The efficiency of AVRs as voltage optimizers
- Educated assumptions regarding the “optimizable” load at a typical industrial or commercial facility
- Data on the impact of supply voltage unbalance on equipment life
- Observations on the average range above optimum of voltage delivered by utilities
- The average cost of carbon

In the tables that follow we will compare three cases.

Base Case: where power is delivered by the utility at optimum voltage and phases are balanced within 1%, but, as is typical, motors run at 50% of capacity.

Typical Case: where power is delivered at 105% of optimum voltage on average and phases are unbalanced at 1.5%.

AVR Optimized and Balanced Case: where an automatic voltage regulator is installed to optimize and balance power as delivered by the utility.

BASE CASE

Power delivered by the utility at optimum voltage, phases balanced within 1% and motors running at 50% of capacity on average.

1. 30kVA load
   a. 10kVA fluorescent lighting
   b. 20kVA 3Ø induction motor running at 50% motor capacity
2. 230V system – power derived at 230V
3. 3Ø voltage balanced within 1%
4. Cost of energy .15$/kVA

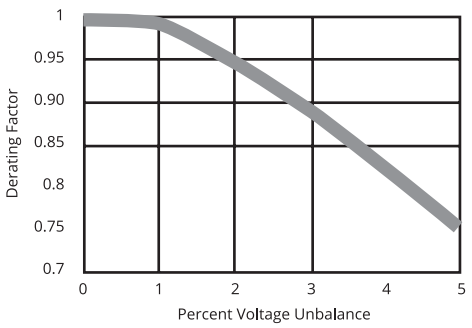
Annual cost of voltage-dependent load

10kVA fluorescent lighting		
(10kVA) (.15$/kVA) (8760 hrs./yr.)	=	$13,140.00
20kVA motors		
(20kVA) (.15$/kVA) (8760 hrs./yr.)	=	$26,280.00
Total annual cost		**$39,420.00**

TYPICAL CASE

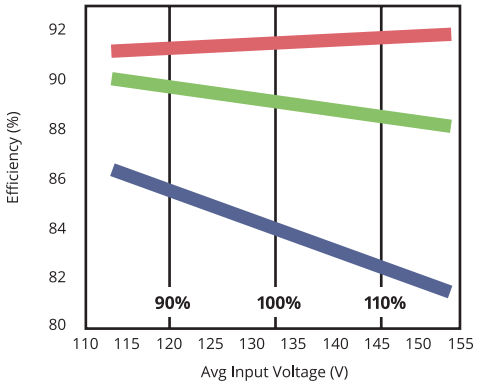
Power delivered at 105% of optimum voltage on average and phases unbalanced at 1.5%.[8]

For voltage-dependent lighting, both incandescent lamps and fluorescent lamps with inductive (or magnetic) ballasts, power is consumed proportionally to voltage supplied.



Motors are less efficient as voltage increases. Furthermore, three-phase supply voltage unbalance increases electrical costs and, more significantly, increases heat generated by the motor, reducing motor life.[9]

1. 30kVA load
   a. 10kVA fluorescent lighting
   b. 20kVA 3Ø induction motor running at 50% motor capacity
2. 230V system – power derived at 105% optimum voltage, or 241.5V
3. 3Ø voltage unbalanced at 1.5%
4. Cost of energy .15$/kVA



8 A supply voltage unbalance of 1.5% would lead to a .0075 electrical cost increase due to degraded motor performance. Greater phase unbalance, which is common in rural areas and at the end of lines would lead to significantly greater cost increases. Graph above from Integral Energy. October 2002. "Technical Note No. 6: Voltage Unbalance."

9 While motors controlled by variable speed devices are voltage independent, and while motors operating with 70%-90% of their specified rating are highly efficient, motors driving industrial processes operate much of the time at partial load, making them both voltage dependent and subject to shortened life spans due to heat generated by supply-side three-phase voltage unbalance. See The Carbon Trust, 2011.

TYPICAL CASE (Continued)

Annual cost of voltage-dependent load

10kVA fluorescent lighting (.15$/kVA) (8760 hrs.)	=	$13,140.00
Additional cost at 105% nominal (10kVA) (.15$/kVA) (.005) (8760 hrs.)	=	$65.00
20kVA motors (.15$/kVA) (8760 hrs.)	=	$26,280.00
Additional cost at 105% nominal (20kVA) (.15$/kVA) (.0075) (8760 hrs.)	=	$197.00
Additional cost at 1.5% phase unbalance (20kVA) (.15$/kVA) (.025) (8760 hrs.)	=	$657.00
Total annual cost		**$40,339.00**

AVR OPTIMIZED AND BALANCED CASE

Power delivered at 105% of optimum voltage on average, phases unbalanced at 1.5%, but where an automatic voltage regulator is installed to optimize voltage at 95% of nominal and balance three-phase power.

1. 30kVA load
   a. 10kVA fluorescent lighting
   b. 20kVA 3Ø induction motor running at 50% motor capacity
2. 230V system – power derived at 105% optimum voltage, or 241.5V
3. 3Ø voltage unbalanced at 1.5%
4. Cost of energy .15$/kVA

Annual cost of voltage-dependent load

10kVA fluorescent lighting (.15$/kVA) (8760 hrs.)	=	$13,140.00
Savings due to optimization at 95% nominal (10kVA) (.15$/kVA) (.01) (8760 hrs.)	=	(131.00)
20kVA motors (.15$/kVA) (8760 hrs./yr.)	=	26,280 .00
Savings due to reduced electrical usage (20kVA) (.15$/kVA) (.015) (8760 hrs.)	=	(394.00)
Savings due to phase balance on motor life (20kVA) (.15$/kVA) (.025) (8760 hrs.)	=	(657.00)
Total annual cost		**$38,238.00**

TOTAL SAVINGS AND ADDITIONAL CONSIDERATIONS

While voltage optimization leads to only modest reductions in energy consumption when compared to a "perfect case," in the real world, where utility power deviates from the ideal, and where variability is actually on the increase as grid managers struggle to compensate for weather-dependent solar and wind power sources, voltage optimization via automatic voltage regulation offers greater value. Relative to a 30kVA load, optimization adds about $2,100 annually in direct energy savings and savings due to extended equipment life.

Notably, these figures do not include savings that would be derived from carbon credits (which would amount to about $1,000 at current EU prices) or from a decrease in the amount of air conditioning necessary to compensate for the extra heat generated by lighting and motors powered by voltage delivered above an optimum level. These figures also do not include savings generated by "peak shaving," or reducing energy consumption during peak demand hours when cost per kilowatt is often higher.

CONCLUSION

Separating spin from science, the automatic voltage regulator (AVR), a reliable and trusted technology proven through more than a decade of use, may provide the most cost-effective option for facility managers seeking to lower

energy costs. While lighting system upgrades and conservation education programs can also lead to significant reductions in energy usage, voltage optimization via automatic voltage regulation may be the fastest, surest and most defensible way for commercial entities to implement power savings and carbon reduction programs.

With electricity at .15$kVA, voltage at 105% optimum on average, and supply voltage unbalance at just 1.5%, at current prices, an intelligent AVR dedicated to a 30kVA load would generate a savings of approximately $2,100 a year *before* factoring in reduced air-conditioning needs, carbon credits or savings due to peak shaving, leading to **a positive ROI in less than three years.**

AN INTELLIGENT AVR DEDICATED TO A 30KVA LOAD WILL GENERATE A POSITIVE ROI IN LESS THAN THREE YEARS

And these numbers are *very* conservative.

Overvoltage of 110% is not unusual, phase unbalance of 5% is often seen in rural regions or at the ends of lines, and electricity costs of .30$kVA or more are common in Germany, Hawaii, New York City and many other regions of the world.

In addition to the direct savings from reduced electrical usage and extended equipment life, the multiple benefits modern, intelligent AVRs provide industrial and commercial customers suggest more serious consideration and general deployment of the devices.

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