Mitigating Risk from Grid Outages with Energy Efficiency Technologies

John Seryak, Go Sustainable Energy LLC

ABSTRACT

Prolonged electrical grid outages can have disastrous affects on industry. Perhaps the most common concerns are the resulting financial losses from lost production and defective products. However, damage to, or loss of, key manufacturing equipment could be even more financially debilitating, forcing a company into bankruptcy. Specifically, this is a serious concern for the many industries dependent on high-temperature processes which require constant cooling. Cooling fluid is typically distributed by motor-powered pumps, which are susceptible to electrical grid outages. Thus, without adequate cooling key equipment can be damaged beyond repair. For example, during the 2003 blackout, one Ohio manufacturer lost a blast furnace which was melted down from lack of cooling. Partially as a result, the manufacturer filed for bankruptcy.

This paper will primarily discuss energy-efficient cooling water distribution as a keystone of mitigating risk from grid outages for industry. Case studies will show how implementation of energy efficiency technologies can dramatically reduce emergency-power requirements of crucial cooling equipment. Additionally, a news archive collection of industrial equipment failures from the 2003 blackout will be reviewed, with special attention given to why equipment failed (when this information is available in the news source) and how energy-efficiency technologies could have lowered emergency-power requirements.

The importance of reducing emergency-power requirements during grid outages should not be understated. The result can be that emergency generators of adequate size are more easily obtained and/or that emergency fuel supplies are sufficient for significantly more time. Therefore, the financial benefit of mitigating risks from grid outages is a strong co-benefit to implementing certain energy efficiency measures.

Consequences in Industry from Grid Outages

Specific Examples of Industrial Problems from Grid Outages

Grid outages, from small disruptions to extended blackouts, are costly to the US economy in general and the manufacturing sector specifically. The Electric Power Research Institute (EPRI) estimates that each year between $104 and $164 billion is lost to outages (EPRI, 2001). The cost to manufacturing is estimated at over $32 billion per year. The average cost per event to a business depends on the duration of the event. EPRI estimates that a 1-second outage event costs the average business about $1,477, a 3-minute outage costs $2,107 per business and a 1-hour event costs about $7,795 per business. This value is an average, and individual businesses can experience costs as high as $1.5 million, with industry bearing the higher costs. Greenberg et. al (2006) also discuss impacts of grid outages due to terrorist attacks.

The August 2003 blackout was a particularly wide-spread and long-lasting blackout. As a result, there were many examples of adverse effects from industries unable to adapt to long-duration grid outages. One of the most striking examples of poor preparedness resulting in extreme costs occurred within the first 30 minutes of the August 2003 blackout. This exemplifies that extremely harsh economic consequences can result from even short-lasting blackouts. Several examples from news publications are reviewed here.

Republic Engineered Products

- Description
  - As published previously in other sources, Republic Engineered Products in Lorain, Ohio lost its ability to cool its furnaces within 30 minutes of the outage. Republic Engineered Products produces special bar steel. Without cooling, molten iron and metal burned through the side of a furnace, spilling on to the plant floor and causing a regionally-visible fire. The company filed for Chapter 11 bankruptcy within two months, citing the blackout as a contributing factor (ELCON, 2004).
- Key Equipment Failure and Efficiency Measure
  - The key process failure in this example was the ability to keep the furnace cool. Cooling water for most steel furnaces is provided either from a lagoon or via a cooling tower. Thus key equipment certainly includes the cooling water pump and potentially a cooling tower. Cooling water pumps are often sized to provide water to a variety of loads. In an emergency situation, cooling needs to be delivered to only key pieces of equipment, such as a furnace. If the pump is not equipped with adequate controls and variable-frequency drives (VFDs), at emergency part-load its power requirements could be close to that of full-load conditions.
  - If the cooling water had been provided, the furnaces would have been allowed to be cooled down adequately without melting and causing a fire, without causing the associated personal safety risks and general area health risks, and in turn reduced the risk of bankruptcy. A source of emergency power, likely a generator, would have been needed. However, the size of the generator could have been reduced, and/or the duration of fuel supplies could have been extended, if the emergency part-load power of the cooling equipment was reduced through energy efficiency measures. For example, it is unlikely that the emergency flow requirements are that of the full-load flow requirements. Thus, equipping the pump with a VFD and proper flow controls could dramatically reduce the emergency power requirements.

BCS Cuyahoga, LLC

- Description
  - BCS Cuyahoga in Cleveland had similar emergency cooling requirements. The damage to equipment and company was not as dramatic as Republic Engineered Products. However, it was reported that BCS Cuyahoga staff had to manually fill reheat furnace cooling jackets to prevent damage to the furnace.
- Key Equipment Failure and Efficiency Measure
  - Clearly, the key process failure in this example was the ability to keep the furnace cool, and obviously includes the cooling water pump.
  - As with Republic, if the cooling water had been provided, the manual filling of the reheat furnace cooling jackets would not have been required, and the risk of

damaging the furnaces would have been greatly reduced. Again, a source of emergency power, likely a generator, would have been needed. And again, the size of the generator could have been reduced, and/or the duration of fuel supplies could have been extended with a VFD and proper flow controls that would reduce emergency power requirements.

Furnace Cooling

- Description
  - This case study is not from the 2003 blackout, though this equipment was in the blackout territory. It exemplifies the potential to reduce emergency power requirements with energy efficiency technologies. An 800-hp pump provides lagoon water to a manufacturing plant with large process heating loads and furnaces. The pump constantly circulates 12,500 gpm, though typically only 7,500 gpm is required by the plant, with the remainder being bypassed back to the lagoon. During nights and weekends the required flow to the plant is reduced to 4,500 gpm. Emergency cooling requirements are likely even less. The power draw of the pump motor is 640 kW. The pump serves key furnaces which require cooling.
- Potential Key Equipment Failure and Efficiency Measure
  - As with the other heat intensive industries, this process requires cooling water to prevent damage to large furnaces. In an emergency situation, flow to the plant can be reduced dramatically. However, in this real-life case the pump was not equipped with a variable frequency drive (VFD). Thus, the pump motor power requirements are 640 kW no matter the flow requirements. If this pump motor were equipped with a VFD, the power draw at 4,500 gpm could be reduced to 87 kW. This is a dramatic reduction in power draw and thus potentially emergency generation requirements.

Typical Generator Ratings and Storage Capacity

Figure 1 presents fuel requirements in gallons per hour versus prime power output at 75% load for various generators. There is a roughly linear relationship. The part-load fuel requirements for a specific generator are similar, as shown in Figure 2, and are approximately 0.067 gallons per hour per kW output. Fuel requirements and power outputs were obtained from a manufacturer website (Kohler, 2009).

Fuel tank sizes for diesel generators are available in various sizes. Fuel storage of 1,000 gallons or less is generally available in sub-base tanks, which are below the generator set. Typical tank sizes may be 1,000-to-2,000 gallons, though custom above and below ground tanks can be built too much larger specifications.

Figure 1. Fuel Requirements versus Power Output for Different Generator Sizes

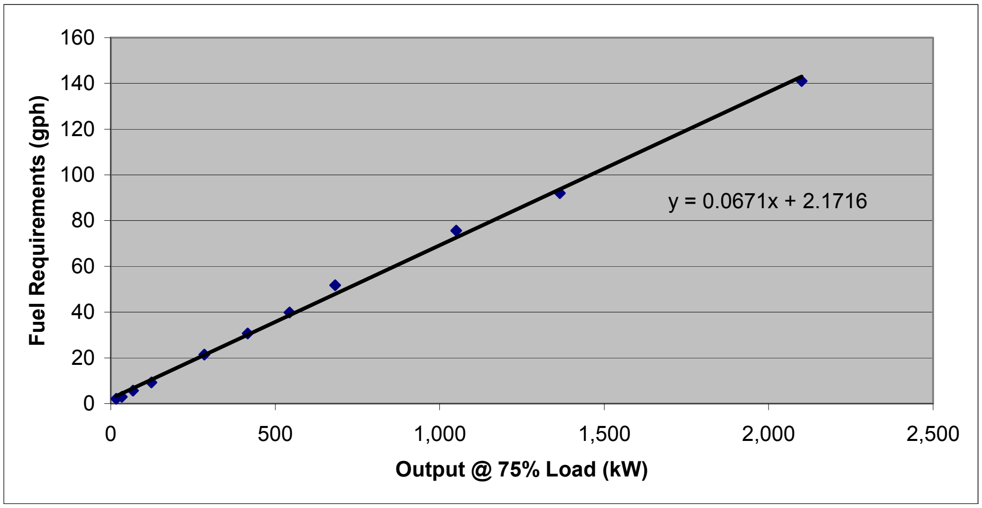
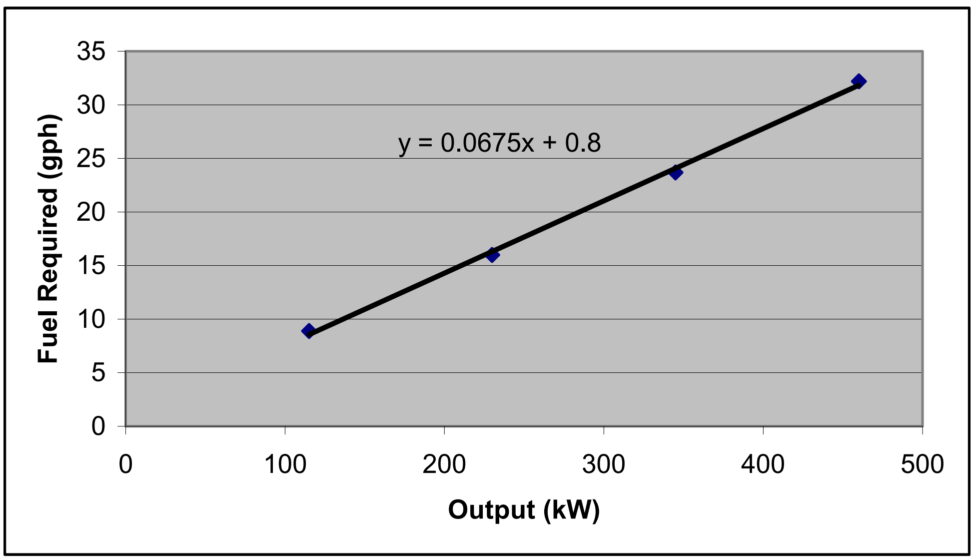


Figure 2. Fuel Requirements versus Power Output at Part Loads for a Single Generator



Power Reduction in Industrial Facilities

VFDs on Plant Cooling Water Pump

The power reduction achievable from energy efficiency measures is substantial, and can dramatically increase the emergency generation time. For example, consider the furnace cooling case discussed previously in this paper. The pump motor which provides cooling water to the plant draws 640 kW. Using the linear equation presented earlier, we can calculate the gallons per hour of diesel needed for a given power output:

$$0.0671 \text{ gph/kW} \times 640 \text{ kW} + 2.1716 \text{ gph} = 45.1 \text{ gallons/hour} \quad (1)$$

As stated earlier, if the pump motor were equipped with a VFD, at the reduced flow rate the power required would only be about 87 kW. At this reduced power draw, there would be reduced diesel requirements and thus a longer achievable runtime from any given size storage tank. Assuming a 1,000 gallon sub-base storage tank, the new diesel consumption rate, the extended emergency generation hours, and the percent increase in generation runtime would be about:

Proposed diesel consumption rate: 0.0671 gph/kW x 87 kW + 2.1716 gph = 8 gph (2)
Baseline operating time: 1,000 gallons / 45.1 gph = 22.17 hours (3)
Proposed operating time: 1,000 gallons / 8 gph = 125 hours (4)
Additional operating hours: (125 - 22.17) hours = 102.8 hours (5)
Percent increase in hours: 102.8 hours / 22.17 hours = 463.7% increase (6)

Other Key Industrial Pumping Applications

Using the above approach, the reduction in the diesel consumption rate, the increase in operation time for a 1,000 gallon storage tank, and the percent increase in runtime was calculated for several pumping case studies. Each of these case studies are from pumping system Energy Saving Assessments conducted at large industrial plants, and sponsored by the US Department of Energy's Industrial Technologies Program. The pumping systems all serve key applications, such as furnace cooling or process applications. As such, maintaining pump operation during an electrical grid outage could be imperative to avoiding equipment damage or lost product. Table 1 presents the recommended energy efficiency measure, the pre and post-efficiency measure power requirement, the reduction in the diesel consumption rate and increase in generation hours. Additionally, the installed cost per kW of emergency generation is presented as well as the net cost per kW of emergency generation once operating cost savings are accounted for. A 5-year lifetime is assumed for these calculations. Though this lifetime is likely very conservative, the economics show that efficiency is very economical even in a conservative case. The cost of electricity, runtime hours and thus annual cost savings for each of these cases was specific to the site, and the full engineering analysis is not presented here.

Most of the examples provided above involve recommending installing VFDs. However, the first and most economical example is to open a throttling valve for a pumping system that already has a VFD installed. While anecdotal, the author's experience has been that many pumping systems with VFDs aren't operating as efficiently as possible. Thus, retro-commissioning systems may be as important as evaluating systems for efficiency opportunities.

While VFDs can clearly reduce the emergency power requirements of a facility, it should be noted that VFDs and other electronic controls can be damaged by grid events. In fact, EPRI (2001) estimates that facilities with VFDs can experience 8-times higher costs from an event. This is likely due to damage of the electronic controls. Thus, installation of VFDs can mitigate risk by reducing emergency power requirements, though if emergency generation fuel is not adequate, these same VFDs are at risk for damage.

Table 1. Pumping Case Study Power Reductions

System	Main Process Pump with VFD	Cooling Water Pump	Cooling Water Pump	Boiler Feedwater Pumps
Recommended Measure	**Open Throttle Valve**	**Install VFD**	**Open Valve & Install VFD**	**Reduce Discharge Pressure, Close Bypass & Install VFD**
Pre-Retrofit (kW)	549	640	52	897.5
Post-Retrofit (kW)	472	87	31	354.8
Power Reduction (kW)	77	553	21	542.7
Reduction in Diesel (gph)	5.2	37.1	1.4	36.4
Increased Runtime (hours)	3.9	102.7	58.5	22.5
Increased Runtime (%)	15%	463%	33%	140%
Estimated Implementation Cost ($)	$0	$120,000	$39,400	$200,000
Estimated Implementation Cost ($/kW)	**0**	**$217**	**$1,876**	**$369**
Normal Operation Cost Savings ($/year)	$47,600	$244,183	$33,900	$153,000
5-year Lifecycle Cost	-$238,000	-$1,100,915	-$130,100	-$565,000
Net Emergency Generation Cost ($/kW)	**-$3,091**	**-$1,991**	**-$6,195**	**-$1,041**

Lighting

Lighting retrofits are another standard energy efficiency measure. Typically, some level of lighting is needed in an emergency generation situation. Industrial facilities typically have a fraction of their lighting fixtures wired as emergency or safety lights. And while industrial lighting is still highly dependent on high-intensity discharge (HID) lighting, emergency lights are often more efficient fluorescent lighting.

Where HID lighting such as 400-W metal halide (MH) fixtures still exists, these fixtures are good candidates for replacement by high-bay T8 or T5 fluorescent fixtures. The power reduction from a standard 400-W MH to a high-bay T8 equivalent is about 222 Watts, a 49% reduction. While the quantity of emergency lighting fixtures in any given facility will vary, the reduction in required power can be significant.

Other Industrial Energy Efficiency Improvements related to Demand Reduction

Patil et al. (2005) discussed the integration of efficiency measures, renewable energy and emergency generation into a focused audit approach for National Grid's (NGRID) Demand Response Program. (Felder and Bloustein (2007) also discuss integrating new technologies with emergency generation).Several industrial case-studies were discussed, including the use of "pre-cooling" to curtail fan and air-conditioning loads to reduce demand by 20 kW and 100 kW in two different facilities. While these case studies were focused on demand response and electricity curtailment as opposed to emergency generation, they do exhibit the potential for efficiency technologies to support demand response and emergency generation goals.

Grid Outage Times

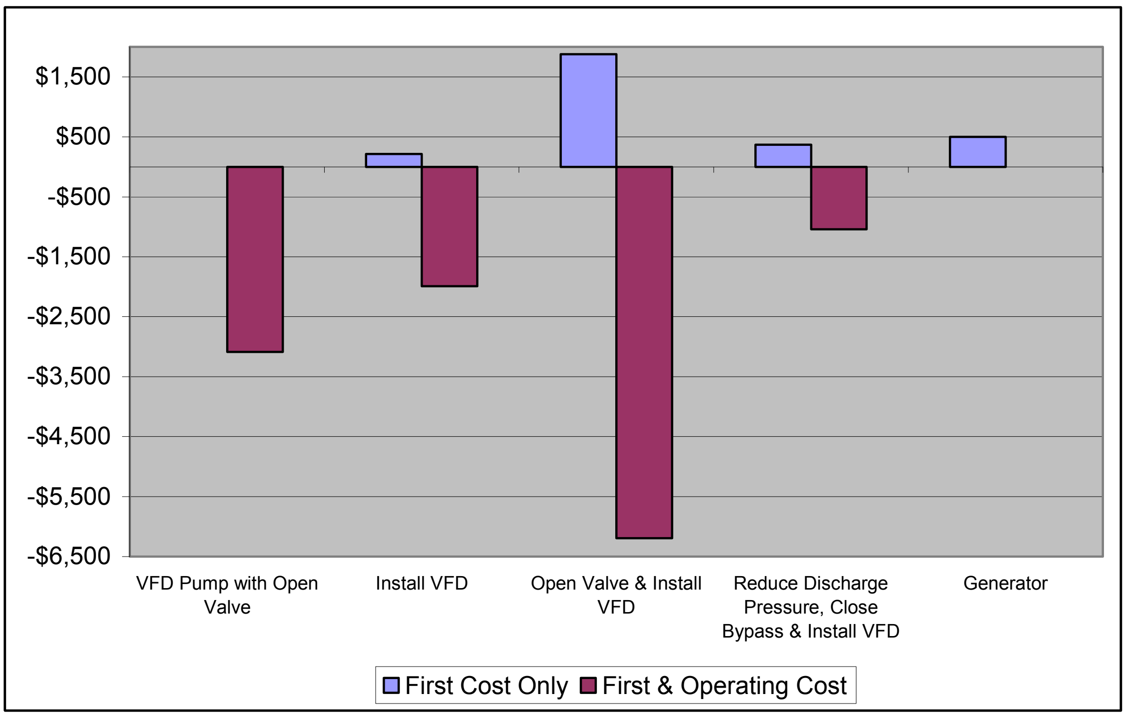
According to EPRI (2001), businesses experience on average 3.9 outages per year. Of these, 20% outages last 1-hour or longer, and only 5% last 4 hours or longer. Energy efficiency would mostly impact the 1-hour and longer outages. At nearly 4 outages per year, with 20%

lasting longer than 1 hour, the average business likely experiences an hour-long outage every two years or so, and experiences a 4-hour+ outage about every 5 years. These events are frequent enough and long enough to warrant study of reducing emergency power requirements.

Installed Cost of Emergency Generation

Emergency generation costs will vary somewhat depending on the size of equipment, associated fuel tank size and the amount of labor required for installing the system. However, it is in general significantly more costly than energy efficiency. For example, demand response incentive costs may be $200 per kW for emergency generation, and these do not cover the full cost of installation. Some vendor websites give approximate installed costs at $500,000 per MW, equivalent to $500 per kW (US Power Production, 2009). Figure 3 presents installed costs for emergency generators versus energy efficiency measures (with and without operating cost savings). Even before operating cost savings are considered, we see that energy efficiency is competitive with emergency generation in installed costs in most cases. When operating cost savings are included, the net cost of meeting emergency power requirements becomes negative.

Figure 3. First Cost and Operating Costs



Existing On-Site Generation Programs

There are many existing federal, state, municipal and utility programs that target on-site generation, though not necessarily emergency generation. These included programs which promote on-site renewable energy generation, combined heat and power (CHP) electricity generation, and demand response programs. In some areas, installation of emergency generators is incentivized to enable participation in demand response programs. For example, the NYSERDA offers incentives of $100 to $200 per kW of installed generation capacity, so long as the site is enrolled in the NYISO Special Case Resource program (NYSERDA, 2008). This type of incentive program is typical of other utility, state agency and independent system operator programs.

The goal of these types of programs is to increase the ability of end-users to reduce electrical loads when the grid is operating near its peak. Many of these programs, including NYSERDA's, offer incentives for permanent reductions in electrical demand from efficiency, or temporary curtailments in usage which often require energy efficient technologies, such as VFDs or advanced controls.

While these programs may utilize on-site generation to address demand reduction goals, or efficiency to meet demand reduction goals, they do not recognize the ability of efficiency to help address emergency generation goals. That is, the programs are centered on utility goals instead of facility goals. Programs centered on facility goals may have better reception than those centered on utility goals.

Conclusions

Energy efficiency technologies can clearly reduce the power requirements of industrial equipment which must be carried by emergency generators during electrical grid outages. In some cases, the energy reduction can be dramatic; in all cases it is significant. In reducing power requirements, the amount of time a facility may stay powered on a given size fuel tank lengthens markedly. As shown in this paper, standard efficiency technologies such as variable-frequency drives can increase generator runtime by 4 to over 100 additional hours. As equipment damage can occur within as little as 30 minutes, in an emergency situation every minute of generation is valuable.

The benefits of integrating energy efficiency technologies with emergency generation can be leveraged by industry in several ways. Most obviously efficiency can dramatically lengthen the carrying time of emergency generators. This additional runtime could reduce the need for additional diesel shipments during a grid outage, or in worst-case scenarios prevent severe equipment damage or product loss. Alternately, the reduction in emergency power requirements could reduce or eliminate the need for additional emergency generation equipment. Moreover, as diesel generators have regulated emissions, reduced power consumption could positively benefit the regulatory compliance and local air quality. Finally, the cost of emergency generation per kW is clearly in favor of energy efficiency when operating cost savings are included. When only implementation costs are considered, efficiency is often though not always a more economical choice.

Given the clear financial and risk mitigation benefits of incorporating energy efficiency with emergency generation, it is surprising that the two elements are not more frequently considered together. There is considerable potential synergy between emergency generation, energy efficiency, renewable energy technologies, cogeneration and demand response. However, at many industrial facilities these related issues are considered separate from each other. There have been some programs which recognize the inter-relatedness of these issues, such as NGRID's Demand Response Program.

In conclusion, we recognize that grid outage events can be extremely damaging to industrial facilities, from lost production, damaged goods and damaged equipment, to the point of contributing to bankruptcy filings. Thus, using emergency generators to mitigate the risk of extreme financial costs from grid outages is of utmost importance to industry. As emergency loads are often inefficient, installing energy efficiency measures can significantly reduce the power requirements. Energy efficiency is much less expensive than diesel generators in meeting emergency power requirements. Energy efficiency can also result in more easily obtaining emergency generators of adequate size or extending emergency fuel supplies. Therefore, the financial benefit of mitigating risks from grid outages is a strong co-benefit to implementing certain energy efficiency measures.

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