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Assessing the Cost of Voltage Disturbances

The modern process industry depends on electric equipment that can be shut down by severe disturbances on the incoming electrical power supply. These disturbances, manifested as voltage dips and sags, can be caused by weather, accidents, or utility equipment failure, and can last anywhere from cycles to seconds or more. The resulting production outages, however, can last much longer.

While the quality of the incoming power supply voltage is fundamentally a technical problem, it is ultimately necessary to make a business decision prior to implementing a fix. Some solutions to voltage dip and sag problems require the use of exotic technology and are expensive. The cost of applying a voltage dip or voltage sag solution to all the power consumed in a facility may be prohibitive. However, if the vulnerability of the process is understood, the system engineer may well determine that only selected critical loads require protection. In some instances, the available solutions may be cost prohibitive, and the right business answer is to do nothing. To decide whether the solution can be justified, the engineer must first determine the cost of business disruptions associated with voltage disturbances.

Assessing the cost of voltage disturbance problems consists of three major elements:

1. Assess the vulnerability of the system to determine the statistical likelihood of interruption events.
2. Characterize the vulnerability to determine the nature of the sensitivity of the system and the most suitable solution.
3. Quantify the value of correcting problems by calculating the expected annual cost attributable to voltage interruptions.

1. Vulnerability Assessment

There are several mechanisms by which a voltage sag or dip can interfere with industrial and commercial processes:

- **Control Error –** Loss of control power results in the inability to control the process. This may well be the most pervasive voltage interruption problem, especially among commercial users.
- **Contactor Dropout –** Many industrial controls employ magnetically-latched contactors as motor control devices. A voltage sip or sag can cause a momentary collapse of the magnetic field which holds the contacts closed. When the contacts open, the motor stops.

- **Voltage Flicker –** In the strictest sense, flicker is the repetitive variation in intensity of lighting, and is more of a human irritation factor than a direct cause of process disruption. However, it can also be used in a more literal sense to describe a set of problems in which lighting is extinguished due to voltage dips.
- **Machine Dynamics –** Since voltage magnitude is essential to transmitting power, voltage dips and sags limit the ability of a power system to distribute power from sources to loads. This limitation in power transfer can lead to generators not being able to maintain stability.
- **Stall and Reacceleration –** Motors will stall if the supply voltage is depressed for a prolonged period. This may be a problem if the motor is not properly protected. Furthermore, motors must reaccelerate when normal voltage is restored. Reacceleration involves higher than normal motor currents which may result in further voltage sag problems.

2. Characterization of Sensitivity

After the process sensitivity to voltage disruptions is understood, the engineer may characterize the sensitivity in two ways. The first dimension of the characterization is the distribution network topology, since the manner in which three-phase loads are served determines the sensitivity of the load to unbalanced voltage dips and sags. Many voltage dips and sags are due to faults on the supplying power system, and the majority of these faults are single-phase-to-ground which cause unbalanced phase voltages. Certain mitigation methods are particularly adept at solving these problems.

The second characterization dimension is duration. The causes of voltage disturbances and the potential solutions are related, and the duration of the disruption is a critical factor. Shorter duration problems tend to be related to a loss of voltage support, while longer duration problems usually involve the system being unable to deliver energy.

The disturbances that cause these outages can be grouped into three general types:

- *Voltage sag* is a partial reduction in the magnitude of voltage that often persists for extended periods and is usually related to system loading conditions
- *Voltage dip* is a significant reduction in voltage for a relatively short duration, often caused by power system faults.
- *Voltage interruption* is a complete loss of input voltage, lasting from seconds to much longer.

Voltage dips and sags generally imply a solution that provides some means of supporting voltage. Interruptions, on the other hand, usually require a source of energy to replace the utility supply.

There are a number of examples where the sensitivity of critical equipment is best described by a composite of the depth of the voltage depression and the duration.

Quantification of this characteristic is difficult. The Computer and Business Equipment Manufacturer's Association (CBEMA) has prepared a curve (Figure 1) which defines ideal maximum tolerance limits for process equipment and ideal minimum levels of acceptable system performance in terms of a composite of depth and duration of voltage depression. This curve is often employed in the power quality field as a performance target, although not all power utilization equipment manufacturers design their products to conform to the CBEMA limitations.

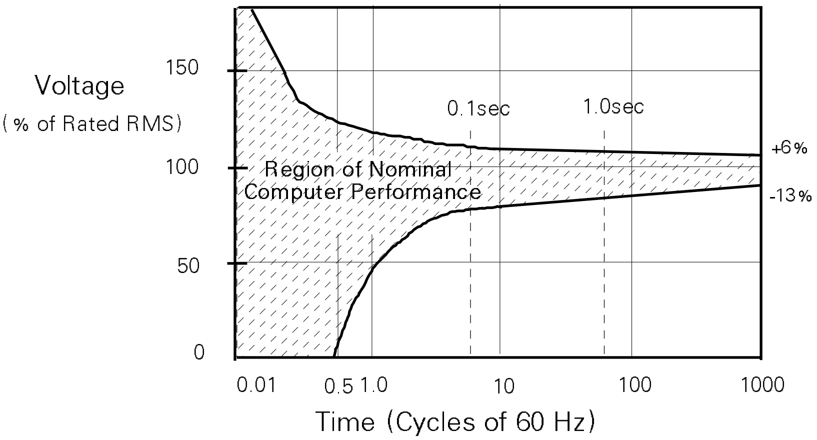

Figure 1. CBEMA Guidelines

3. Economic Evaluation

The actual economic justification for prevent production interruptions due to voltage disturbances must consider the following elements:

1. How vulnerable is the process to various types of voltage disturbances?
2. What is the net cost of production outages due to these disturbances?
3. How effective is a particular solution in avoiding these outages?
4. How does the cost of the solution compare to the savings which can be realized?

There are several elements of cost associated with a voltage interruption that should be recognized and quantified in the economic evaluation.

- **Cost of Lost Production –** In the simplest case, this is the incremental margin on product that is not manufactured and therefore cannot be sold.
- **Cost of Damaged Product –** If the interruption damages a partially completed product, the cost of repairing that product must be recognized. In some cases, the product cannot be repaired, so the value of the raw materials (including the consumed energy up to the point where the disruption occurred) must be

accounted for together with the cost of the incremental value added to the product. In the commercial arena, a major source of concern is lost computer data.

- **Cost of Maintenance –** The cost of reacting to a voltage disruption experience. This includes everything involved in restoring production, including diagnosing and correcting the problem, cleanup and repair, disposing of damaged product, and environmental costs.

  In some industries (e.g., plastics and electronics), an interruption for several hours may result in the need to invest many days and thousands of dollars in cleaning up the process system before it can be returned to service.

- **Hidden Costs –** This factor may be the most difficult to quantify but it can easily be the most significant. If the impact of the voltage dip or sag is control error, it is possible that the impact on product may not be apparent until the product is in the hands of the consumer. Product recall and/or public relations costs can be significant.

The underlying events that lead to voltage interruptions are generally random. An effective way to put risk and expenditure on a common basis is to assess the statistical risk of a voltage interruption (this mathematical treatment is beyond the scope of this document). Determine the statistical expectation of events that cause voltage interruption *and* can be addressed with a given solution.

It is usually best to identify those problems that are responsible for the majority of the cost of the outages, and apply the solution that most efficiently addresses those outages. Historical data, such as production records, are a prime source for this information. If multiple events occur, the mathematical treatment will require that the average duration of each event be determined. Then, the annual cost attributable to voltage interruptions that can be addressed by a common solution is:

$$\text{Expected Annual Cost} = (\#\ \text{Events/Year}) \times (\$/\text{Event})$$

If management practices require that expenditures be justified with a payback rate of N years, the amount that can be justifiably spent is:

$$\text{Justified Expenditure} = (\text{Expected Annual Cost}) \times N$$

This Application Note is one of a series being produced by GE Power Systems Energy Consulting to address specific issues in power quality affecting utility, industrial, and commercial businesses. Other notes are available on:

- Applying Voltage Disturbance Remediation Systems
- Increase the Reliability of Power Distribution to Critical Loads

For copies of the above bulletin, for a complete and up-to-date listing of available bulletins, or to discuss specific concerns on areas of power quality or electrical power systems, please contact:

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