Power Quality

A guide to voltage fluctuation and light flicker

Scope

This guide provides a simple introduction to the theory of how light flicker is produced and how it is perceived. It includes a description of the international standards that define how voltage fluctuation should be measured and what levels are needed to reduce light flicker to acceptable levels. There are also sections describing what you can do to prevent or reduce the impact of voltage fluctuation.

Introduction

One of the many aspects of power quality that can affect electricity users is voltage fluctuation that causes lights to flicker. Whenever the electrical load changes, the supply voltage is affected proportionately. Most people have seen this occur in their house; when the refrigerator or the furnace starts, some of the lights may dim. If a large enough change occurs, such as the start-up of a large industrial motor, lights can dim or brighten, not only for that customer, but all over town. Normally the customer whose load is changing is the most affected, but other customers are all affected to some degree, depending on how large the load change is and how close they are to the changing load.

If large voltage changes occur in rapid succession, light levels will vary, and when the variation becomes large enough to be noticeable or annoying, the effect is called light flicker. Experience has shown that most people are tolerant of an occasional dip in the lights, but when flicker is frequent or continuous, they begin to complain.

How flicker is perceived

The response of the eye

Like other human senses, the eye has amazing capabilities. Without conscious thought, our eyes can adapt to light levels varying by a factor of 10,000 from bright sunlight to faint starlight. Despite that enormous dynamic range, we can detect variations in brightness of less than 1%. Even more impressive, dedicated parts of the brain filter the incoming information, removing background clutter and extracting the most important features. Our eyes are also extraordinarily sensitive to rapid change. As the light level gradually drops by a factor of 100 at dusk, we may be almost unaware of the change, but a 1% step change in ambient light level due to a sudden change in voltage will almost certainly attract our attention.

Fundamental constraints on the response of the eye limit our perception of very rapid events. The mechanisms of converting light into nerve impulses take a finite time to occur, so the brain has averaging mechanisms that smooth out the time delay between nerve impulses, presenting us with a constant picture, despite the “bucket brigade” nature of the incoming signals. As a result of this automatic smoothing, pictures displayed in rapid succession appear continuous, an effect that movies and television use to good advantage.

Gaps shorter than about 50 milliseconds (1/20 of a second) are filled in, as our processing system ignores them as it would variations in nerve impulses, and averages them out.

We are, therefore, quite insensitive to changes that occur at frequencies above about 20 cycles per second. It is no coincidence that our television and electric lights run at 60 cycles per second, fast enough that they do not appear to flicker.

The net result of the balance between averaging and pupil adaptation is that our sensitivity to changing light levels increases the faster they change, up to the point where the finite response time of the eye and the automatic smoothing mechanism begin to come into effect. This begins to occur at about 9 cycles per second, the frequency at which we are most sensitive to light flicker.

The effect of voltage on light output

There is one more level of complication involved when we consider the effect of variations in supply voltage. Since we are concerned with the effect of light flicker caused by voltage changes, we must consider not only the perception process, but also the conversion of electricity into light, and the way that the output level of a lamp depends on the power supply voltage. Different lamp types (incandescent, fluorescent, arc lamps) respond differently, but in general the light output is proportional to the power consumption, although the power is not necessarily proportional to the voltage. In ballasted lamps, such as arc lamps and fluorescents, the ballast stabilizes the power, which is therefore more or less proportional to the voltage.

Incandescent lamps act like resistors, so the power is roughly proportional to the square of the voltage (actually, the dependence is changed slightly by the fact that the resistance increases as the filament temperature increases).

As a result, incandescent lamps tend to be the most sensitive to changing voltage, and so flicker calculations are based on incandescent lamps as a worst case.

An incandescent lamp produces light by passing electric current through a tungsten filament until it glows white-hot. We tend to think that when we turn on the switch, the light comes on instantly, but in fact it takes around a tenth of a second for the filament to heat up completely. Like any other object, it has a certain amount of thermal inertia, although because it is small, the time it takes to heat up is short.

As we have seen, moderately fast changes are the most visible, and the filament time constant is close enough to the frequencies of interest that it must be taken into account. Thermal inertia provides another smoothing mechanism that reduces the impact of higher-frequency changes and slows down step changes.

The thermal inertia depends on the size and shape of the filament, and so this term dictates a slightly different response curve in Europe, where 220-volt lamps are used, from North America, where the standard is 120 volts.

Figure 1 shows the light output of an incandescent lamp when the 60 Hz power is turned on. After the filament warms up, the light output has a substantial amount of flicker. Note that because the filament heats equally with positive and negative voltages, the flicker frequency is doubled to 120 Hz, too fast to be visible to the human eye.

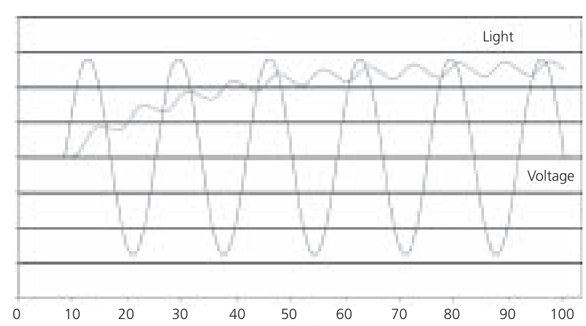

Figure 1. The light output of an incandescent lamp during starting

The threshold of perceptibility

All of these factors taken together determine how likely a given level of flicker is to be noticed by an observer. It is difficult to classify levels of visibility; the only quantitative measure is to determine the threshold of perceptibility. This can be done in a scientific way by presenting observers with a light source that has variable amounts of flicker and asking them to press a button or make a signal when the light seems to flicker. Different individuals have different sensitivities, so trials with a number of observers are required to achieve repeatable results. The threshold of perception is defined as the amount of flicker that is perceptible to 50% of observers.

These experiments have been performed in numerous studies, and a standard flicker perceptibility curve, shown in Figure 2 below, has been drawn based on the results. The curve shows the percentage voltage variation at the threshold of perception for different flicker shapes and repetition frequencies.

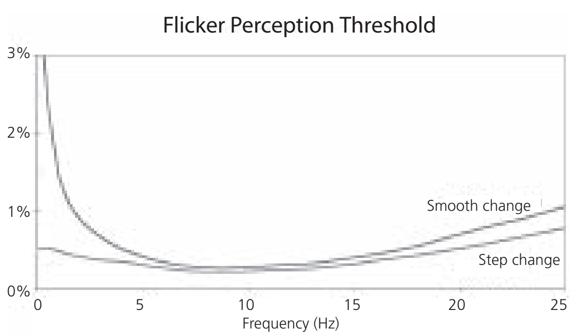

Figure 2. Flicker perception threshold vs frequency

The tests can be done with two types of flicker: smooth sinusoidal variations, or square waves with sharp step changes, as shown in Figure 3. As you might expect, smooth variations are much less perceptible, especially at low frequencies, where the adaptation of the eye tends to conceal the changes.

At frequencies near the peak sensitivity (8.8 Hz), voltage variations as small as 0.2% can be perceived. At higher frequencies, the thermal inertia of the lamp filament and the averaging of the eye mean that larger changes must occur before they are visible. For square variations, the response at medium to high frequencies is quite similar to that for sine waves, but a little more sensitive. At low frequency, step changes appear as independent events, and the threshold of perceptibility levels off at a constant value of 0.5%.

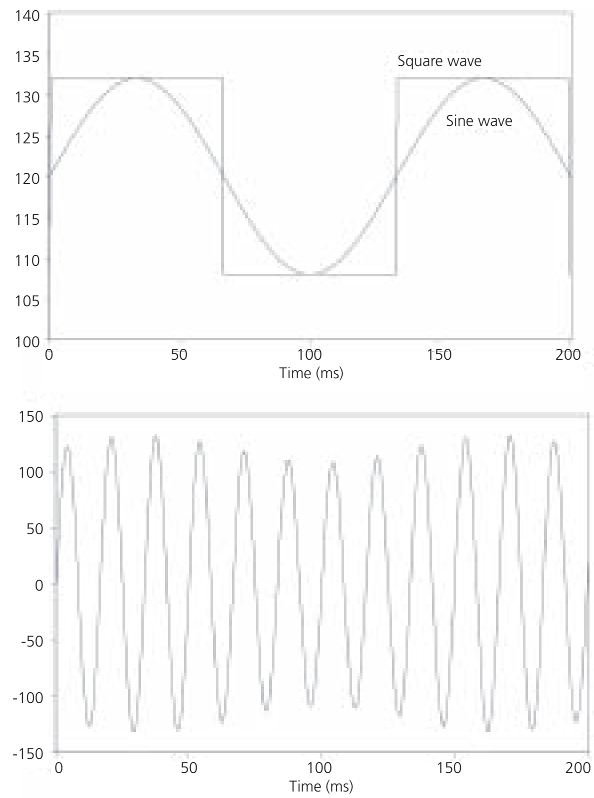

Figure 3. Test voltage waveforms for flicker perception

How flicker is produced

Voltage fluctuation basics

Voltage fluctuation, or variation in the voltage at the electrical outlet, can be caused by events at many different points in the power distribution system. For most consumers, power generated by many large generators comes to them through a high-voltage electrical transmission network, or grid. Power flows through this grid at voltages around 100 or 200 kV to a substation, where the voltage is reduced by a transformer to a lower voltage, typically 12 to 25 kV. It then flows through an underground or overhead distribution system until it reaches a distribution transformer, where it is reduced further to the consumer voltage (typically 120/240 V in a single-phase service or 120/208 V or 347/600 V in a three-phase service). The power then flows through a service conductor to the customer's meter and distribution panel and through the building electrical system to the outlet or light fixture.

The voltage at the outlet is determined by two factors: the generator output voltage and the voltage drop, or loss, in the transmission and distribution system.

Rapid variations in the generator output voltage occur very infrequently. BC Hydro manages voltages at different points in the grid to maintain maximum efficiency and proper flow of power, and changes to voltage and power flow are carried out slowly in a controlled manner. Generators are equipped with automatic voltage regulators to maintain output voltage levels despite changes in load, and BC Hydro has voltage regulators in its distribution system.

It is only when a major event, such as a transmission line outage due to a lightning strike or mechanical failure, occurs, or when system demand is greater than the combined available generation capacity, that the regulators are unable to maintain the voltage. Under these conditions there may be a temporary undervoltage or overvoltage until the condition is corrected, or, in the worst case, the system may become unstable, causing some areas to lose power completely and other areas to separate from the grid. Fortunately, this type of event is extremely rare – even one or two events a year is considered unacceptable – and corrective action is taken to prevent future repetitions.

Most voltage variations are caused by changes in the voltage drop in the distribution system. Each component of the system has losses associated with it, and produces a voltage drop that is approximately proportional to the current flowing through it. The ratio of voltage drop to current flow is called the impedance, and can conveniently be expressed as the percentage drop in voltage at rated current. Transformer impedances vary; for example, an impedance of 10% means that the output voltage of the transformer will be 10% lower when it is fully loaded than when it has no load.

The output voltage of a 120 V distribution transformer with 10% impedance might vary from 126 V at no load to 114 V at rated load. Distribution lines, service conductors and house wiring each produce a voltage drop as well, typically around 3% each at full load. For these impedances, the total voltage drop from the grid to the outlet, if every component were loaded to its maximum limit, would be 19%.

In practice, most of the distribution system components are normally loaded to around 50% of their rating, and because the total distribution load is the sum of many customer loads, the voltage drop is usually fairly stable, in the range of 5% to 10%. Individual customer circuit loads vary from 0 to 100% of rated load, but even in a single house it is quite unlikely that all the appliances and lights would be on at the same time, so the total load of a single customer might vary from 10% to 90%.

Loads change all the time, through manual switching, thermostats or changes in motor loads. When you push a piece of wood through your table saw, the current increases substantially as it tries to keep the blade spinning against the increased resistance, and the current drops again when the resistance ceases. In the same way, industrial loads such as wood chippers or conveyer belts draw more or less current, depending on the motor loading. Any time a load changes, it affects the voltages throughout the electrical system, although most of the changes are so small as to be undetectable.

Let us take as an example your 3/4 hp, 120 V table saw, plugged into an outlet in the workshop. When the saw is switched on, it probably draws about 30 A, or twice the current rating of the circuit, for a second or so, then drops back to about 3 A at idle. The 30 A momentary current will increase the current draw throughout the system.

The magnitude of the current increase in the distribution line is reduced by the distribution transformer ratio. For a 14.4 kV line, the ratio is 120:1, and the load current surge will be 0.25 A at 14.4 kV.

If we assume the substation transformer is rated for 1,000 amps with a 10% impedance, this will create a voltage drop of (0.25/1,000) x 10% = 0.0025% at the transformer output. A typical distribution line one mile long might have an impedance of 3% at a rated current of 300 A, for a further voltage drop of (0.25/300) x 3% = 0.0025% at the distribution transformer. It is clear that the impact of the load change on the overall power system is undetectable.

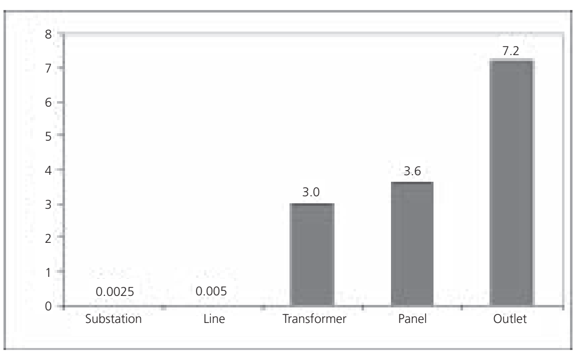

Figure 4. Total voltage dip at different points

As we get closer to the load, the effects become greater. A typical small pole-mounted residential distribution transformer is rated 100 A at 120/240 V, and if we assume 10% impedance, the starting surge will create a voltage drop of about (30/100) x 10% = 3%.

Several houses probably share the transformer, and each of them will see a momentary 3% dip in voltage, large enough that your neighbours' lights will flicker.

The service conductor to a house usually has about 2% impedance at 100 A, so all the lights in your house will see an additional dip of 0.6%, for a total of 3.6%. Number 14 wire has a rating of 15 A and an impedance of about 0.06% per foot, so if there is a lamp plugged into the same outlet as the saw, 30 feet from the panel, the wiring will drop the lamp voltage by a further 3.6%, for a total dip of 7.2%. Figure 4 illustrates the voltage drops in this example.

This illustrates how voltage variations propagate through the system. The closer you are to a varying load, and the farther from the substation, the more you will be affected. Most flicker and voltage variation problems affect the customer whose load is changing, or his or her immediate neighbours. The exception, and the most difficult case to deal with, is when a commercial or industrial load has frequent changes that are large enough to affect the voltage on the distribution line, and therefore to impact all the customers sharing that line. As the example illustrates, this occurs only with large load changes. Given the distribution system described above, to reach the threshold of perception (about 0.5% change for an isolated event), a distribution current surge of about 25 A would be required. For a three-phase load, this is equivalent to a load change of about 1 MW, or the starting current on a 300 hp motor.

Common flicker sources

Isolated events such as motor starts and process shutdowns can cause changes in voltage, but these isolated events are not classified as flicker. The public does not generally see these events as a major annoyance, as long as the voltage changes are infrequent and not large enough to cause problems other than minor perceptible light flicker.

The most difficult sources of repetitive flicker are large loads that fluctuate at frequencies in the vicinity of the peak sensitivity region, near 10 cycles per second. The classic example is an arc furnace, which has a large random variation in load current due to the nature of the arc. The variations are erratic, but often include substantial components in the range of 1 to 20 cycles per second. For a furnace located in an urban area with a strong distribution system, flicker may become a concern at load levels around 1 MW or more. Any arc furnace located far from a substation on a relatively weak line could be a source of flicker and should be checked for possible flicker problems.

Another fairly common flicker source is a wood chipper that chops wood into chips for pulp and paper or for waste wood disposal. These machines consist of a chipping wheel driven by a large motor. As the wood is fed in at intervals, the motor current changes as the chipping wheel is loaded or unloaded, and affects the voltage as shown in Figure 5.

The fluctuation rate depends on the feed material and mechanism, and may produce flicker in the sensitive frequency range. Since they are mostly rural, many of these plants are located at the end of weak distribution lines, and are therefore possible flicker sources, even if the load is only in the range of 100 hp or so.

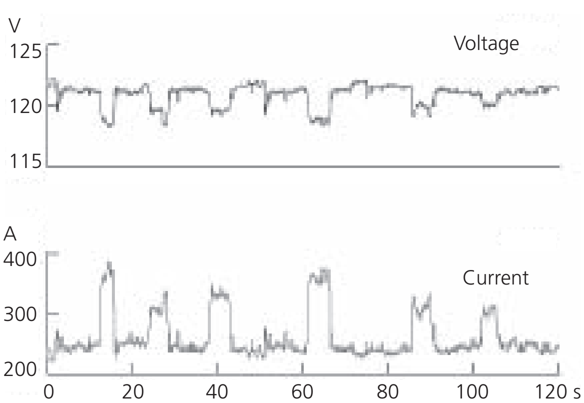

Figure 5. Wood chipper voltage fluctuations

Electric heating, either process heating or space heating, is a potential source of flicker, but in most cases this heating is controlled in a rather slow cycle by a thermostat or process controller, and the changes are infrequent enough to avoid the most sensitive frequency range. If the load is large and the impedance is high enough, however, electric heating can be a source of annoying flicker, especially in the same building. Particular care should be taken with electronic thermostats, since they can have very fast control cycles. Controllers with cycle times of a few seconds or less should be avoided, since their load cycling can lead to high levels of local flicker.

Periodic variations at higher frequencies that are close together can produce flicker at their "beat", or difference, frequency, like two guitar strings tuned close together. This effect is primarily a concern with multiple adjustable speed drives running at slightly different frequencies, say 50 and 55 Hz.

On the source side, diesel generators can contribute to voltage fluctuations, particularly if there are variations in the fuel supply.

These are just a few examples – other load types can also produce flicker if the conditions are right. The key thing to look for is frequent load changes of substantial magnitude in relation to the distribution line capability. Whenever this type of load is on line, the potential for flicker is there.

Types of voltage variation

Flicker sources in the power system may generate smooth changes or step changes, and anything in between, and the shape has an impact on flicker perceptibility. A load such as a wood chipper is a good example of a square wave flicker source. As each piece of wood feeds into the chipper, the power demand increases suddenly when the chipper bites into the wood, and then drops quickly back to no load when the piece is consumed.

Loads using modern adjustable speed drive controls, on the other hand, tend to resemble the sine wave variation, since most drives have adjustable ramping limits that produce a smooth, controlled acceleration and deceleration to minimize stress on the equipment as well as flicker. In many cases, the flicker shape is not a regular periodic change, and a complicated mathematical calculation is required to estimate the threshold of perceptibility.

Figure 6 shows an example of an irregular RMS* voltage variation that was measured when an irrigation pump started on a rural distribution line. This sort of variation needs a more advanced treatment than simply looking it up on the perceptibility threshold curve.

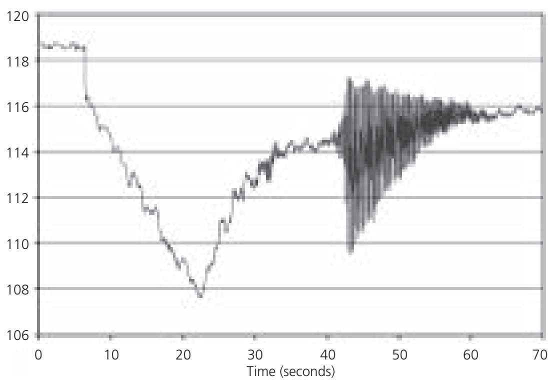

Figure 6. An irregular motor starting voltage transient

Non-repetitive events

In the standards, it is clear that flicker refers only to repetitive variations in the power supply voltage. Occasional individual events such as motor starts, utility circuit switching and equipment failures or trips, if they are not repeated on a regular basis, are specifically excluded from the category of flicker.

This is not to say that occasional voltage changes do not affect power quality; they should certainly be monitored and kept down to tolerable levels. Such events should be treated in the same way as other disturbances like undervoltage, overvoltage, transients and outages. The most common event of this type is the starting current surge for an infrequently started motor. Guidelines are available for the maximum voltage dip on motor starting. In a new motor installation, the voltage dip should be calculated from the starting current and system impedance, and if the guidelines will be exceeded, a soft-start mechanism, such as reduced-voltage starting, should be applied.

* RMS (root means square) – refers to the most common mathematical method of defining the effective voltage or current of an AC wave.

Flicker measurement

Early flicker measurement

In the early days of the power system, measurement and analysis tools were primitive. Problems with flicker occurred from time to time, and engineers of the day developed empirical guidelines as to what levels of flicker were tolerable and what levels would likely lead to complaints. In keeping with the tools at their disposal, the parameters they used were simplified.

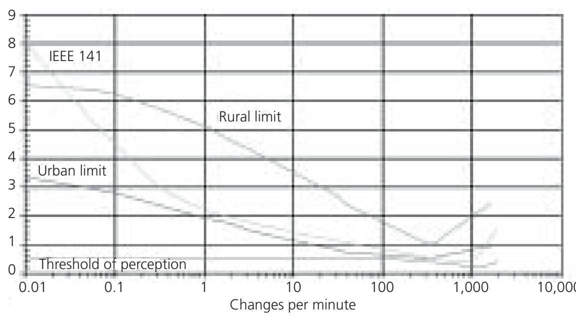

Figure 7. Typical rule-of-thumb flicker limit curves

The guidelines were based on the number of voltage changes per minute (or per second or per hour) and the percentage voltage change.

Curves were drawn to show the allowable number of changes of a given magnitude. Figure 7 shows some typical examples of this type of curve. In this figure, the curve labelled “IEEE 141” is the “Borderline of irritation” curve from Figure 3-8 of IEEE 141. The “Urban limit” and “Rural limit” are curves historically used by BC Hydro’s distribution department. The “Threshold of perception” curve is taken from the curves shown in the IEC flicker standards.

This system, while simple in concept, has several obvious shortcomings. Clearly there are some approximations made in simplifying a series of events (especially complex ones like those shown in Figure 6) into a single magnitude and repetition rate. As we have seen, there are also significant differences in perception for step changes as opposed to gradual changes, so the slope of the transition should also be taken into consideration.

Another concern is how to combine different components, for example, if you have a large change every 10 seconds and a smaller change every second. There is also the question of how to deal with episodic flicker, where you may have rapid changes for a few minutes once an hour, or once a day.

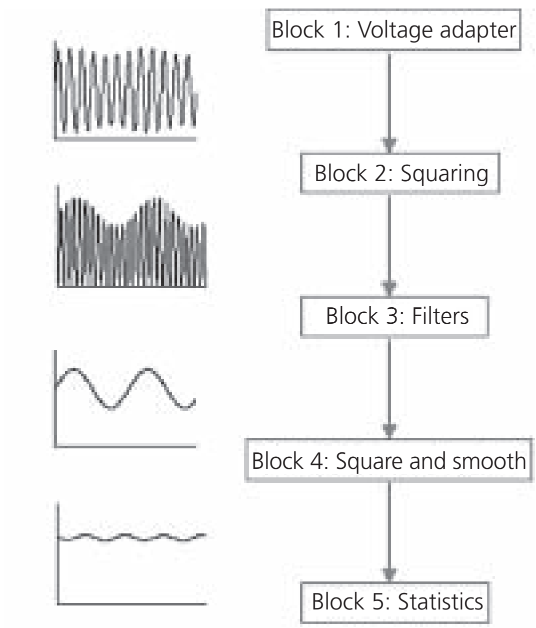

Figure 8. The IEC flicker meter

The IEC flicker meter

To address some of these issues, the International Electrotechnical Commission (IEC) introduced standard IEC 868, *Flickermeter functional and design specifications*, in 1986. The standard defined the design and performance of a measuring instrument for flicker. The intent was for the meter to be used at the lighting location of interest.

A block diagram is shown in Figure 8. The IEC flickermeter monitors a single-phase voltage signal, which is passed through rectifier, filter and conditioning circuits to produce a signal proportional to the RMS voltage.

This RMS voltage signal is further processed to filter out the base level and measure the amount of voltage variation that is occurring.

The voltage variation signal is then passed through a series of filters that approximate the perceptibility curve shown in Figure 2. The resulting output signal is called the instantaneous flicker sensation P, and has a value of 1.0 at the threshold of perceptibility, whatever the flicker frequency. This signal can then be fed to recording, averaging and statistical analysis circuits. The flickermeter standard did not define the statistical analysis to be done, but provided a capability for statistical analysis.

Statistical measures of flicker

In 1991 the IEC issued standard 868-0, *Flickermeter part 0: Evaluation of flicker severity*, which defined the statistical analysis and criteria for maximum acceptable flicker levels for a 230 V, 50 Hz system. In this document, a statistical analysis based on a ten-minute sample is used to calculate the parameter P_{st}, the short-term perceptibility index. This index is calculated from a combination of five percentile values, i.e., the P value exceeded 50%, 10%, 3%, 1% or 0.1% of the time during the ten minutes. In this case, a value of 1.0 for the P_{st} index represents the level at which flicker is seen as annoying by most observers. Below that level, there may be times when flicker is perceptible, but it should be rare enough that it is not annoying. In cases where the flicker has a large long-term variability, sampling can be done over an appropriate long interval, and the series of P_{st} values can be averaged using a cube law average (i.e., cube, then average, then take the cube root). This ensures that occasional intervals of annoying flicker are given appropriate weighting.

Present-day standards

In 1994 the IEC reorganized the flicker standards into IEC 61000-3 and 61000-4-15. The basic content of the standards has not changed, but the standards have been updated and the numbering has been revised to conform to the overall IEC numbering scheme and fit in with other power quality standards. The IEEE has two standards that deal with flicker, IEEE 141 and IEEE 519, but they are moving to adopt standards compatible with IEC. IEEE task force P1453 has developed a flickermeter definition appropriate to 120 V, 60 Hz systems, and is currently working on adopting a standard compatible with the IEC. The IEC is working on changes to incorporate 120 V, 60 Hz systems.

Flicker source identification

When light flicker occurs, one of the challenges is to identify the source of the flicker so that corrective action can be taken.

In some cases there may be only a single large fluctuating load, and the source of the flicker will be obvious, but in other cases there may be multiple large loads connected to a line on which flicker is observed. In this case, conventional flicker measurement techniques have little to offer, but advanced methods can provide a solution.

If a monitor that can measure currents as well as voltages is installed, the current drawn by each load can be monitored along with the line voltage.

After recording one or two major load changes, the line voltage can be plotted against load current. The source impedance can then be calculated, i.e., the change in voltage per amp of load change. Once this is done, the voltage fluctuation caused by that customer can be calculated from the load current variations. By comparing the calculated fluctuation with the measured fluctuation, a direct measurement can be made of the percentage of the total fluctuation due to the customer being monitored, as shown in Figure 9.

In a complicated system, each customer can be monitored either in turn or simultaneously, and the contribution of each load to the flicker can be determined, so that appropriate measures can be taken.

This technique provides an additional benefit: proposed changes to the supply or the load can be evaluated. Load current variations multiplied by the impedance provide an estimate of the resulting flicker levels.

Changes to the supply system will change the source impedance in a predictable way, and the impact of those changes on the voltage fluctuation can be predicted, taking into account measured load current variations. Recording currents along with voltages gives the system designer a whole new set of tools to use in dealing with flicker. Figure 9 shows some sample voltage and current waveforms and how they can be used to separate internal from external disturbances.

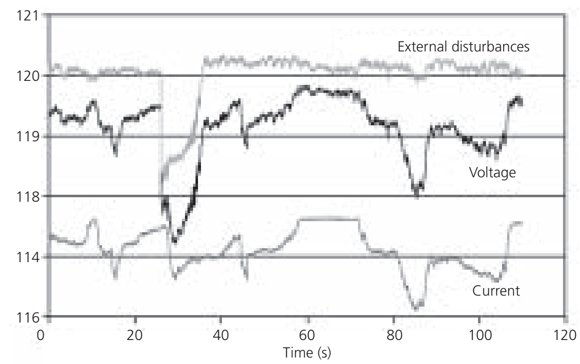

Figure 9. Flicker source identification waveforms

What you can do to reduce flicker

As described in the section on how flicker is produced, load changes have the greatest impact on the voltage in their immediate vicinity. In consequence, the first electricity customer to suffer from voltage flicker is often the customer whose load is causing the flicker. As a rule of thumb, for typical source impedance at the customer panel in the range of 5% to 10%, a load change of about 10% of the panel rating will cause visible light flicker. For a residential customer with a 100 A service, load changes of around 10 A, or 1 kW, would qualify, while for industrial or commercial customers the level increases in proportion to their total load. If repetitive load changes of this magnitude occur, you are likely to suffer annoying flicker levels. The visible flicker level is determined by the magnitude of load changes as well as the source impedance in common between the changing load and the lighting circuit. If you are suffering from local flicker, therefore, you have three basic strategies to choose from: reducing the load changes, reducing the source impedance, or decoupling the load from lighting circuits.

Reducing the load changes

Flicker magnitude is influenced by three characteristics of the load changes: the magnitude, the speed of the change, and the repetition rate. You may be able to control any or all of these to reduce the impact of the flicker. It is sometimes possible to split up a large load, thus reducing the magnitude and/or speed of the change. For example, a large compressed air bank might have three motors, all controlled by the same pressure switch so that they start and stop together.

By simply changing to three independent pressure switches, set at slightly different points, the starts and stops can be staggered, substantially reducing the resulting flicker. Similar strategies can be used for many loads like heaters, refrigerators, pumps and compressors, which are not time-critical. In some cases it may be difficult or costly to break up the load, but in other cases a small investment in controls may provide a substantial benefit in flicker reduction. Some of these strategies can pay off in conservation as well, running only a portion of the load unless the full power is needed, and thus reducing the losses.

Other options include using soft-starters, reduced-voltage starting of motors or installing variable speed drives with slow starting ramps. With a manufacturing process, it may be possible to slow or stagger the process start through simple program changes.

Reducing the source impedance

For most low-voltage equipment, the majority of the source impedance is in the service drop, step-down transformer and low-voltage wiring.

If long distances are involved, the voltage drop in the low-voltage wiring can be substantial, and you might consider increasing the conductor size, which will not only reduce fluctuation on loads sharing those conductors, but will also reduce losses and result in some energy savings.

The transformer impedance depends mainly on the size of the transformer, so the higher the transformer rating, the less flicker a connected load will produce on the secondary side of the transformer. In some cases it may be appropriate to change transformers, or switch loads between transformers, to minimize flicker.

In general, the higher the voltage, the lower the effective impedance, so there may be cases where increasing distribution or end-use voltage will provide an effective remedy.

Reducing the coupling

The flicker induced in a light source by a changing load depends on the impedance that the two loads share. Often the simplest solution to local flicker, or even to area flicker, is to change the source connections for the lighting load. Industrial and commercial sites often have several supply transformers, which allows for some flexibility. If the site has one large fluctuating load, feeding that load from a dedicated transformer, or at least removing all lighting loads from that transformer, can eliminate or greatly reduce flicker. The worst case of lighting loads connected to the same circuit as the fluctuating load should definitely be avoided, and lighting circuits should be powered from a flicker-free circuit or transformer whenever possible. Another possibility is changing phases, since most lighting is single phase. Simply changing phases to a phase with a smaller variable load may reduce flicker problems substantially in some cases.

Lighting changes

Occasionally, flicker can be perceived because the type of lighting used is especially sensitive to voltage fluctuations. If other remedies are very expensive and the area of flickering lights is limited, then changing the type of lighting could be explored. Perhaps the most sensitive type of lighting is incandescent lighting on a common thyristor-based dimmer switch. If reduced lighting levels are desired, sometimes staged or blocked fluorescent lighting can achieve the same effect as incandescent light dimming.

Active countermeasures

Recent advances in power electronics have led to the availability of several different brands of static voltage compensators (SVC). These devices use solid-state switching of inductors or capacitors to rapidly compensate for changing line load, thus stabilizing the distribution voltage. The principle is the same as with switchable line compensation capacitors or tap changers, but they operate quickly enough to reduce voltage flicker substantially.

These compensators are expensive, but they may provide a cost-effective alternative to upgrading lines when simpler remedies fail. Figure 10 shows an example. In addition to reducing flicker, static voltage compensators have been reported to improve productivity of an arc furnace by 15% to 17% by supplying energy to the arc so that quicker, more efficient melts occur. This increase in productivity typically pays for the SVC in less than two years.

A number of large electrical equipment companies manufacture flicker compensators. At present these include the ABB Statcom, the Mitsubishi D-Statcom, and the Siemens Dstatcom. Experience with these devices is limited, but a number of prototype installations have been in service for up to a few years.

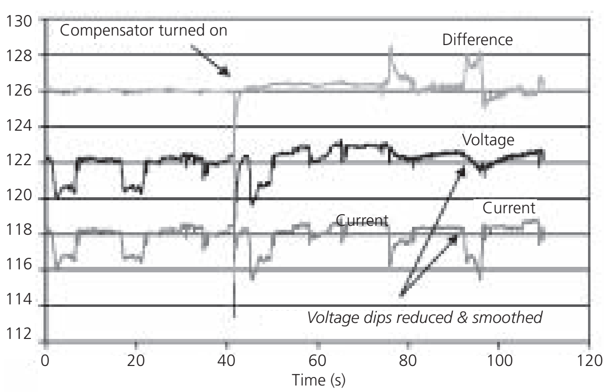

Figure 10. The effect of active compensation

Planning ahead to avoid flicker

The most cost-effective way of dealing with flicker is to avoid it in the first place. Anytime large variable loads are added to a distribution line, there is a potential for flicker. A new load of this magnitude usually requires consultation with BC Hydro prior to installation, and that is the ideal time to identify and deal with potential flicker problems. The first level of screening is to look at the magnitude of voltage change that can occur due to load variation. This is determined by multiplying the load change by the source impedance.

If the maximum voltage change (excluding infrequent events) is less than 0.2%, it is unlikely that any visible flicker will occur. If large voltage changes can occur, the situation should be reviewed by BC Hydro staff or consultants to determine more accurately whether flicker problems are likely.

If so, remedial measures can be implemented, and the costs can be properly assessed against the new load.

Following this process, you can make informed decisions about the cost and benefits of the new load, and, with BC Hydro, you can devise the most effective means of avoiding flicker problems.

References

A number of publications are available containing more detailed information on flicker. The most definitive information is in the standards listed below. There are also several textbooks and handbooks available through the IEEE web site. The article "Voltage and Lamp Flicker Issues," available on the web, contains an excellent technical review of the issues involved in applying the IEC standards in a North American context. Anyone interested in becoming involved in the process should visit the IEEE task force website and contact a member of IEEE task force P1453 for further information.

Websites

IEC home page: www.iec.ch

IEEE home page: www.ieee.org

IEEE task force home page:
grouper.ieee.org/groups/1453

Handbooks

IESNA Lighting Handbook – 9th Edition, Illuminating Engineering Society, 2000

Articles

S.M. Halpin, R. Bergeron, T. Blooming, R.F. Burch, L.E. Conrad, T.S. Key, "Voltage and Lamp Flicker Issues: Should the IEEE Adopt the IEC Approach?", http://grouper.ieee.org/groups/1453/drpaper.html

M. Sakulin and T.S. Key, "UIE/IEC Flicker Standard for Use in North America: Measuring Techniques and Practical Applications", Proceedings of PQA'97, March 1997, Columbus OH.

G.F. Reed, M. Takeda, J.E. Greaf, T. Aritsuka, T. Matsumoto, Y. Hamasaki, Y. Yonehata, A.P. Sidell, R.E. Chervus, "Application of a 5 MVA, 4.16 kV D-Statcom system for voltage flicker compensation at Seattle Iron & Metals", IEEE Summer Power Meeting, July 2000

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