PQTN SOLUTION

Load Interactions
Arcing Switch Contacts
Oscillatory Transients

Power Quality
Testing Network

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Solving the Fast Clock Problem

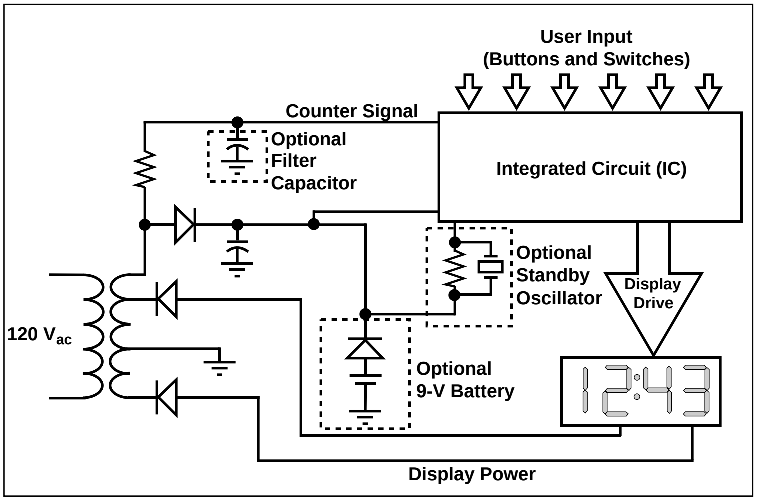


Figure 1.

Schematic Diagram of a Typical Digital Clock

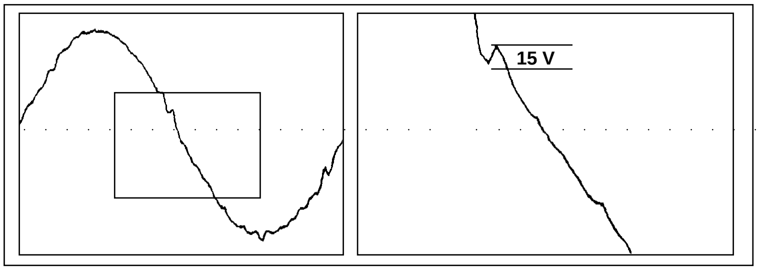


Figure 2.

One of the Many Notches (15 Volts Peak-to-Peak) Discovered on the Sierra Blanca Power Lines

Background

Digital clocks, one of the most widely distributed electronic products, are common not only in stand-alone models but also as functional parts of many modern consumer products such as microwave ovens and video cassette recorders. Thanks to advances in microelectronics, today's digital clocks are cheaper, more compact and more rugged. Still, their performance can be affected by certain power quality problems.

Although there are many manufacturers and models, most digital clocks share a basic circuitry that makes it possible for power quality troubleshooters to diagnose power quality problems affecting digital clocks and to come up with general solutions (see Figure 1). One wide-spread complaint of electric utility customers is that their digital clocks run fast. At first a mystery, the direct reason for these fast-running clocks has been solved by troubleshooters in the field and in the laboratory.

Here's how the problem arises. The counter of a digital clock converts the incoming 60-Hz sine wave into a square wave that it uses for its timing reference. Each time the incoming sine wave completes 60 cycles, the counter registers one count and advances the clock by one second. Some oscillations or notches on the sine wave can trigger the counter, causing it to count at two or three times its normal rate (see Tutorial, back page).

Oscillations that cause digital clocks to run fast can be caused by both end-user appliances and events along distribution lines. For example, appliances that use high-voltage discharging, such as electronic air ionizers, or electronic switching and voltage notching, such as uninterruptible power supplies (UPSs), may distort the sine wave powering digital clocks connected to the same electric utility circuit or common service transformer. One-time distribution events such as capacitor switching will only trigger a clock's counter once or twice—if at all—while the arcing of faulty distribution switches can double or triple the counting rate for hours at a time.

A number of fast-clock episodes experienced by various electric utility engineers have been presented to the Power Quality Testing Network for further investigation. In all cases, engineers solved the problems using available knowledge and resources. However, the final solution may come from manufacturers in the form of a small, immunity-enhancing capacitor that shunts unwanted oscillation current to ground.

The Problems: Part 1

Some rural customers in Sierra Blanca, Texas, complained to the local utility company that their digital clocks were gaining up to two hours a night and awakening them with alarms too early in the morning. Troubleshooters for the utility borrowed the malfunctioning clocks and installed them in the company's Sierra Blanca office, where they operated perfectly. Company engineers then used a harmonics meter and an oscilloscope to check the local power lines. The oscilloscope revealed voltage oscillations at about 15 volts peak-to-peak (see Figure 2).

The voltage oscillations varied from cycle to cycle, but only showed up on one phase. Using one of the malfunctioning digital clocks, the engineers confirmed their theory that the clocks were mistaking the oscillations for additional cycles and speeding up . However, the engineers encountered a complication: the farther from the substation in all directions, the faster their clock ran.

The engineers also noted that as the distortion grew worse, the clock ran faster. They identified similarly distorted waveforms in a power quality analyzer field handbook, but the problem-causing notches were not nearly as repetitious as any of the illustrated distorted waveforms. The source of the distortion was difficult to trace.

Monitoring the voltage at the substation, the engineers transferred different branch power lines to other feeders (backfed them), one by one. The problem disappeared when a particular branch power line was isolated. Later, the engineers discovered a partially open disconnect switch on the affected phase and confirmed that arcing between the contacts of the switch was distorting the sine wave.

Several residents of Salisbury, North Carolina, had complaints similar to the West Texas customers. Engineers from Duke Power, the electric utility serving Salisbury, found that the clocks of their customers—located up to a mile apart—ran fast only during certain hours and that all of the affected residences received electrical service from the same phase of a particular three-phase, 24-kV circuit from the Salisbury substation. Duke workers installed power monitors at points along the circuit and in several residences.

The Duke power monitors captured the disturbing waveform at one point along the distribution circuit (see Figure 3) and at an electrical outlet of a residence (see Figure 4). Duke engineers analyzed it and discovered another clue: The waveform occurred only when Step B of the capacitor bank at the substation was switched off. However, they could not yet pinpoint the exact source of the distortion making the clocks run fast.

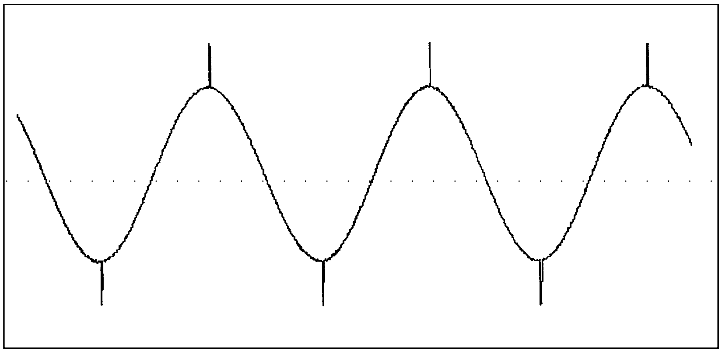


Figure 3.

Ringing on a 60-Hz Waveform Captured by the Duke Power Engineers on the Distribution Lines

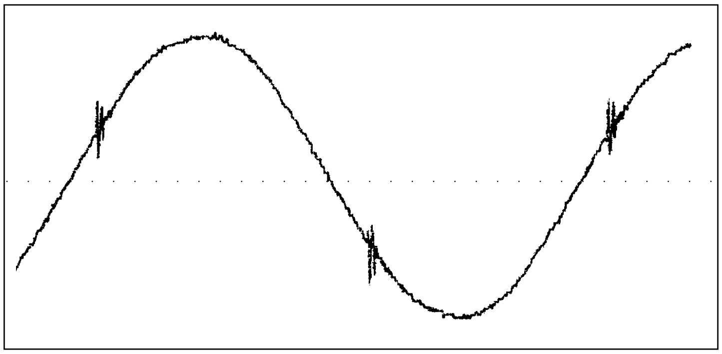


Figure 4.

Ringing on a 60-Hz Waveform Captured by the Duke Power Engineers at a Residential Electrical Outlet

The Power Electronics Applications Center (PEAC) was then conducting tests on digital clocks at the request of another utility. One of the Duke engineers called PEAC and asked for assistance with the fast-clock problem in Salisbury. The engineer faxed the captured waveform to PEAC, and a Duke customer donated one of the fast clocks to be analyzed and tested.

PEAC engineers succeeded in reproducing the waveform—a short (1 to 2 millisecond) oscillating burst—and powered several digital clocks with it. A 50-volt power line disturbance created a corresponding 3.5-volt, 2-millisecond oscillation in the waveform at the input of the clocks' counters. The PEAC engineers tested expansion and contraction of the waveform to determine the limits of the clocks' sensitivity to the disturbance.

The test results supported a theory that Duke Power had come up with back in Salisbury: The waveform was caused by periodic arcing. Engineers at Salisbury went to the capacitor banks at the substation, where they confirmed their theory. Arcing was causing a pulse event every few cycles of the 60-Hz sine wave. At each pulse event, the distribution circuits resonated, causing oscillation at the customer service transformer capable of disrupting the time-keeping of digital clocks.

The Solutions: Part 1

At Sierra Blanca, the West Texas engineers discovered random capacitive arcing across the faulty disconnect, which created the oscillations in the power lines of a few rural customers. The oscillations causing their digital clocks to run fast were eliminated when the engineers properly closed the disconnect.

Based on the signature of the disturbance confirmed by PEAC, knowledge of their substation equipment, and their experience, the Duke Power engineers were able to isolate the problem by inspecting circuits at the substation. They correctly deduced that the arcing was caused by a failing vacuum bottle in a capacitor bank breaker. When they located the problem vacuum bottle, it was blackened and close to failure. Service personnel replaced the vacuum bottle without disruption to Salisbury's electrical service, avoiding the costly situation of the vacuum bottle failing and disrupting service to the customers.

The Problems: Part 2

In Wisconsin, an electric utility customer reported that his parents were plagued by a digital clock that ran at approximately twice the expected rate. The customer had taken a storage oscilloscope to his parents' home and recorded voltage notches at the outlet feeding the clock. Because he saw the same voltage notches at the main breaker, he believed that they were coming from outside the house. He faxed the engineers at Wisconsin Electric a copy of the voltage waveform from the main breaker, similar to the waveform shown in Figure 5. The notches in the waveform reminded the engineers of a waveform seen at the site of an industrial customer, where a six-pulse, AC-to-DC converter was causing voltage notching four times per second and ringing at about 10 kHz.

The Wisconsin Electric engineers at first believed that the voltage notches at the customer's house were probably caused by something in the house, but eliminated that possibility when they found out that the notched waveform had been recorded on the line side of the residence main breaker with the breaker off. Because there was no industrial facility fed from the same service transformer, the engineers eliminated industrial processes as a source of distortion.

The engineers recorded the same notched waveform on both phases of the service entrance. Moreover, similar waveforms were present on a neighbor's meter socket. The notching was present at the secondary of the service transformer as well. However, another nearby transformer, which was connected to the same single-phase primary line, had an undistorted secondary voltage. The engineers concluded that the primary voltage was not to blame.

Because the voltage notches were at the meter even when the main breaker was open and similar impulses were at neighboring meters, the Wisconsin Electric personnel removed a neighbor's meter as a test. The voltage notches at the clock vanished. By switching the neighbor's breakers off one by one, the search for the disturbance was narrowed to an electronic air ionizer.

Several customers of the Public Service Electric and Gas Company (PSE&G) in Newark, New Jersey, found that they had fast-running digital clocks and asked the utility for assistance. Field personnel discovered a disturbance on the supply voltage sine wave in every house with a fast clock. In the case of one customer, the source of the disturbance was traced to a neighbor's electronic air ionizer. The utility obtained an identical ionizer and conducted some experiments, finding that operating it would cause some digital clocks to run fast. PSE&G asked PEAC to conduct system tests to understand and define the problem to encourage the manufacturer of that particular ionizer to modify it.

PEAC researchers took a systems approach, not simply to test an individual ionizer but to look at a system that consists of a disturbing load, a sensitive load, and various utility system conditions. The test results confirmed that the high-voltage discharges of the ionizer were responsible for the bursts of impulsive transients in the supply voltage.

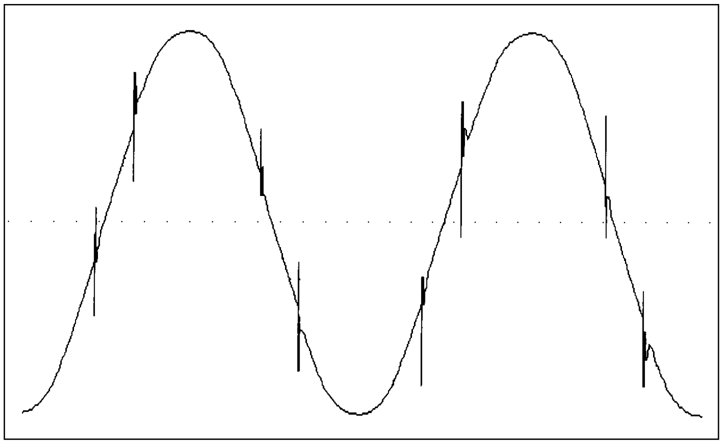


Figure 5.

Waveform Captured at Residence of a Wisconsin Electric Customer

The Solutions: Part 2

In Wisconsin, the problem was solved simply because the neighbors volunteered to forego using their air ionizer. The Wisconsin electric utility had its service representatives ask everyone with fast-running clocks powered by a common service transformer whether they had an electronic air ionizer. This turned out to be cheaper than tracking each recurrence of the problem.

PEAC's testing of several off-the-shelf digital clocks and one of the disturbing electronic air ionizers for PSEG led to a different solution. PEAC engineers discovered that when an LC filter was added at the ionizer supply voltage input, all clocks maintained accurate time. Further, some clocks were immune to the voltage notches and oscillations. The immune clocks contained a low-pass filter (a capacitor and resistor) that attenuated the ionizer emissions. PEAC recommended that PSE&G replace fast-running clocks with models containing low-pass filters.

Significance

Voltage disturbances that can corrupt the timing signal of digital clocks can be attributed to many different sources. In the case of the West Texas utility, the oscillations that sped up the clocks were the same as the oscillations identified by the Duke engineers. At the Texas substation, the oscillations were caused by arcing from an open disconnect on a branch line over 20 miles away, while the arcing at Duke's Salisbury substation was caused by a faulty vacuum bottle up to five miles away. In the Wisconsin and New Jersey fast-clock cases, and in reports from several other utilities, similar notches on the 60-Hz sine wave were caused by electronic air ionizers in neighboring residences.

PEAC's test results demonstrate that adding inductance to the source, adding series inductance at the ionizer, installing an LC filter at the ionizer, and installing a capacitor in the digital clock all eliminated or mitigated the voltage oscillations that cause digital clocks to run fast. While installing a filter at the ionizer effectively attenuates the notching that causes digital clocks to

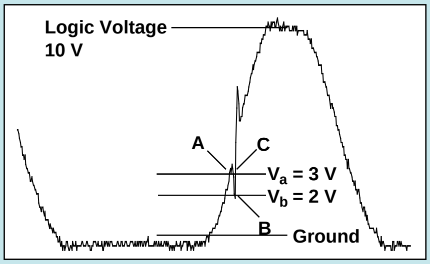
TUTORIAL: *Anatomy of a Fast Counter*

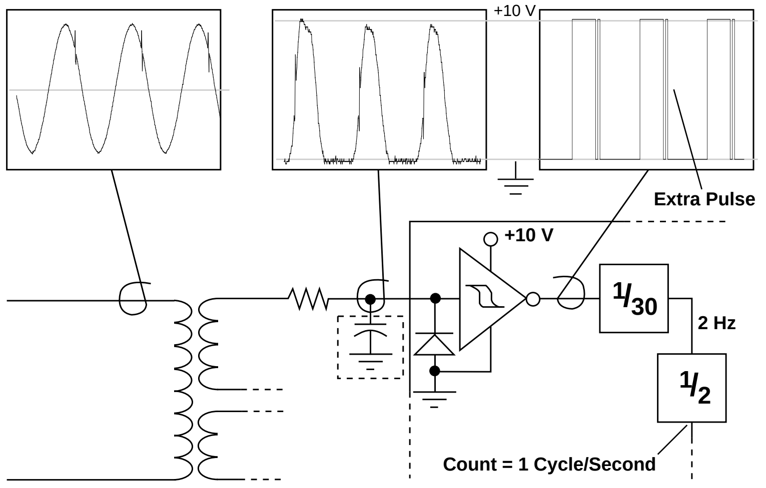
A single integrated circuit controls the timing of a typical digital clock. Electronics engineers designed the IC to exploit the precision of 60-Hz, sinusoidal power generated by electric utilities, which maintain this sinusoidal frequency within strict limits. However, the IC in a digital clock is much more complicated than a divide-by-sixty circuit. The heart of the counting process is a type of logic gate, such as a NOT gate (inverter) or a buffer, with Schmitt trigger characteristics. As shown in the truth table, the output of an inverter is high (ground) when the input is high and low (logic voltage) when the input is low. The logic output of a buffer follows the input voltage. A logic gate without Schmitt characteristics determines whether an input is high or low based upon a preset reference voltage. When the input voltage crosses this reference voltage, the output changes state (from low to high or high to low). Any voltage fluctuations occurring around this reference voltage play havoc on the logic gate, causing it to change state regardless of the fundamental input frequency. However, a Schmitt trigger—in this example an inverter—has two different reference voltages—one when the gate output is low (V_a) and another when the output is high (V_b). These two reference voltages create two “safe” windows (logic voltage to V_b and ground to V_a) within which the input voltage may oscillate without causing the gate to change state.

Truth Table

Inverter	
Input	Output
HIGH	LOW
LOW	HIGH
Buffer	
Input	Output
HIGH	HIGH
LOW	LOW

For example, if the output of the inverter is high and the input crosses V_a (3 volts), the output goes low and will remain low until the input crosses V_b (2 volts). Voltage fluctuations between 2 and 10 volts will not cause the output to change state. What if the voltage fluctuations extend beyond the 8-volt window? Then, as shown in the figure (right), the inverter changes states three times instead of one—once each at points A, B, and C. In a digital clock without a filter capacitor, such voltage fluctuation can cause the counter to double-count because the inverter produces an extra counting pulse for every cycle of the input signal, as shown below. A filter capacitor installed from the inverter input to ground can mitigate such fluctuations to within the safe window.





NOTES

run fast, the cost of skilled labor to select, purchase, and install the filter rules out this remedy for most electric utilities and their customers. As another alternative, the utility may suggest that its customer acquire a filter from the manufacturer of a disturbing appliance. To eliminate an ionizer as a source of power system disturbances, ionizer manufacturers should consider installing such a filter during product assembly.

Because most of the newer digital clocks contain RC low-pass filters, the most cost-effective “quick fix” is replacing the customer’s clock with a clock that incorporates such a filter. The final solution to the fast clocks is for the clock manufacturers to design immunity to voltage oscillations and notches into their products. Perhaps with a little nudging from utility advocates, all digital clocks of the future will have built-in protection from troublesome sine wave distortions.

ACKNOWLEDGMENTS

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