

Ground Current, Power Quality, and Other Issues Associated with Solar Inverters

Dave Stetzer

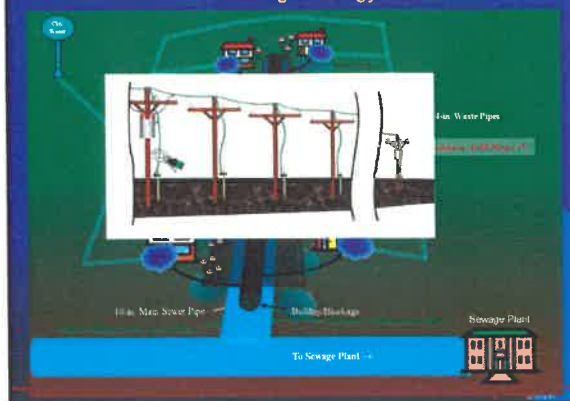
Stetzer Electric, Inc.
Blair, Wisconsin, USA
dave@stetzelectric.com

Stray **X** Voltage?

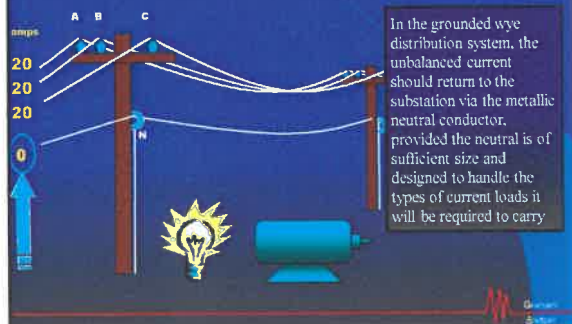
Ground Current

Ground Current Explained

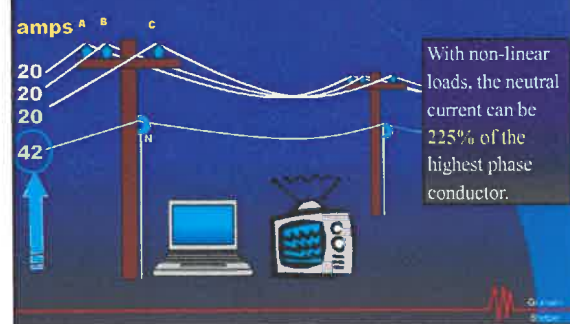
A Sewage Analogy



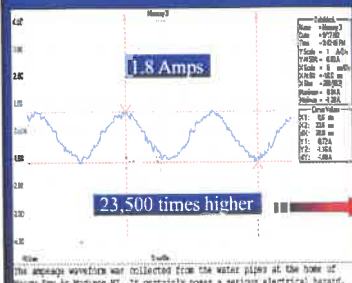
Wye System - Linear



Wye System - Non-Linear



Where Ground Current Flows
... water pipe in homes ...



- The waveform shown at left was collected from the water pipes of a Madison home
- 80 μ A causes heart arrhythmia (Reilly 1998)

The leakage waveform was collected from the water pipes at the home of Mary's son in Madison, NJ. It certainly poses a serious electrical hazard.

Where Ground Current Flows
... through human body ...



80 micro Amps

The smallest current having an observable effect (heart rhythm disturbances) occurs at 80 μA in humans (Reilly 1998).

Minnesota Study

Final Report of the Science Advisors to the Minnesota Public Utilities Commission:

Research Findings and Recommendations Regarding Claims of Possible Effects of Currents in the Earth on Dairy Cow Health and Milk Production

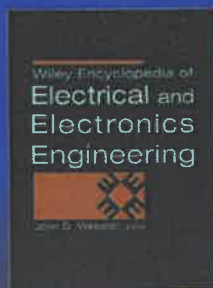
July 31, 1998
Minnesota Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, Minnesota 55101-2147

70% of phase current returns via the earth

Ground Current and Power Quality

The Rules

Wiley Encyclopedia



"It is an unsafe practice to allow current to flow over the earth continuously, uncontrolled. All continuously flowing current must be contained within insulated electrical conductors."

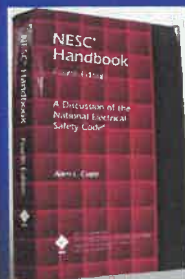
National Electrical Safety Code (1997)

National
Electrical
Safety
Code

Rule 92D: Current in Grounding Conductor

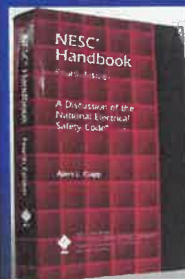
“Ground connection points shall be so arranged that under normal circumstances there will be **no objectionable flow of current** over the grounding conductor.”

National Electrical Safety Code Handbook



- "Rule 92D refers to actions required in the case of 'objectionable' flows of current over the grounding conductor. The word 'objectionable' is undefined in the NESCC; it is left to the designer's discretion, utilizing good design and operating practice, to identify and remedy the situation."
- "...areas that are often known to present specific problems (such as milking barns without adequate voltage gradient control, pipelines, electric railways, conduits, etc.) may need special attention to limit damage to equipment or uncomfortable conditions for personnel or animals."

National Electrical Safety Code Handbook



- From Rule 215B: "Objections to use of the earth as part of a supply circuit are made from both safety and service standpoints."
- When earth returns were used in some rural areas prior to the 1960s, they became notorious offenders in dairy areas because circulating currents often caused both step and touch potentials. In some cases, these have adversely affected milking operations by shocking the cattle when they were connected to the milking machines, and have affected feeding. The grounding methods required by the NESCC, including the use of a metallic neutral throughout each span of a multi-grounded wye system, reduce the opportunity for such occurrences.

Ground Current



1960s: Linear Loads

- 100 amps current on phase conductors
- 100% returned via ground
- 100 amps via ground



1990s: Non-Linear Loads

- 1000 amps current on phase conductors
- 70% returned via ground
- 700 amps via ground

IEEE 519-1992

Institute of Electrical and Electronics Engineers

IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

Sponsors
Transmission and Distribution Committee of the
IEEE Power Engineering Society
and
Static Power Converter Committee of the
IEEE Industry Applications Society

Approved June 18, 1992
IEEE Standards Board

Approved January 4, 1993
American National Standards Institute

Since most electronic equipment is located at a low voltage level of its associated power distribution system, it is frequently exposed to the effects of voltage notching. Voltage notches frequently introduce frequencies, both harmonic and nonharmonic, that are much higher than normally exhibited in 5 kV and higher voltage distribution systems. These frequencies can be in the radio frequency (RF) range, and, as such, can introduce harmful effects associated with spurious RF (page 39).

IEEE 519-2014

Institute of Electrical and Electronics Engineers

IEEE STANDARDS ASSOCIATION

IEEE

Table 1—Voltage distortion limits

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0 \text{ kV}$	5.0	0.0
$1 \text{ kV} < V \leq 69 \text{ kV}$	3.0	5.0
$69 \text{ kV} < V \leq 161 \text{ kV}$	1.5	2.5
$161 \text{ kV} < V$	1.0	1.5*

*High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

Source: IEEE Std 519-2014, IEEE Std 519-2014

Sponsored by the
Transmission and Distribution Committee

Ground Current and Power Quality Problems

A SIGNIFICANT OFFENDER

Solar Panels



How Solar Works (Utility-scale)

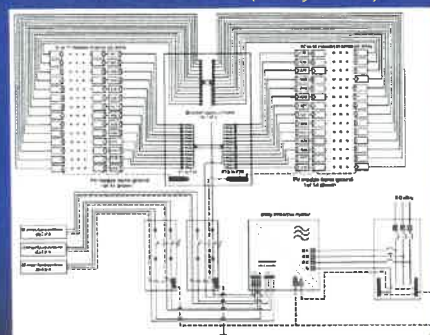


Diagram 2 Three-line wiring diagram for a 250 kW commercial PV system with a single 3-phase inverter

Image taken from: John Bortone, From kW to MW: System Design Considerations, Solar Pro Magazine, June 1, 1, Oct/Nov 2009, <http://www.solarprofessional.com/articles/design-considerations-for-kw-to-mw-system-design-considerations-16-Nov-2009>

How Solar Works (Residential Grid-tied)

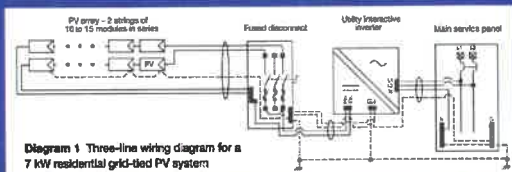


Diagram 1 Three-line wiring diagram for a 7 kW residential grid-tied PV system

Image taken from: John Bortone, From kW to MW: System Design Considerations, Solar Pro Magazine, June 1, 1, Oct/Nov 2009, <http://www.solarprofessional.com/articles/design-considerations-for-kw-to-mw-system-design-considerations-16-Nov-2009>

Harmonics and Noise in PV Inverters

Solectria Renewables White Paper

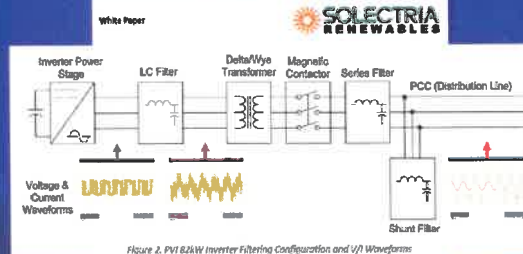
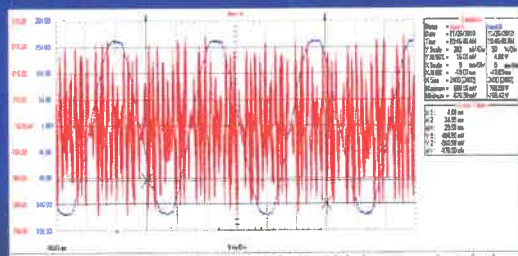


Figure 1. PV 6.2kW Inverter Filtering Configuration and V/I Waveforms

Figure 1. PV 6.2kW Inverter Filtering Configuration

Solar Panels On

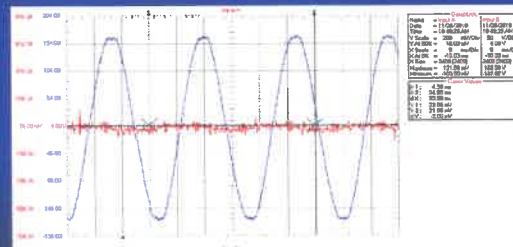
Graham-Stetzer Meter Reading 1999+



When, Solar Panel ON, Input A (red wave) is the high frequency electrical pollution riding on the 60 Hz 120 volt sine wave. Input B (blue wave) is the 60 Hz 120 volt sine wave.

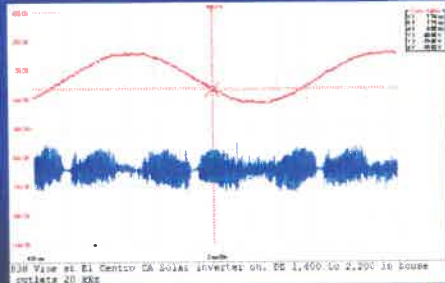
Solar Panels Off

Graham-Stetzer Meter Reading of 44

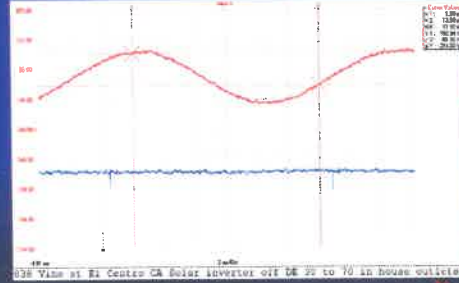


When, Solar panel shut off, input A (red wave) is the high frequency electrical pollution riding on the 60 Hz 120 volt sine wave. Input B (blue wave) is the 120 volt 60 Hz sine wave recorded at the receptacle.

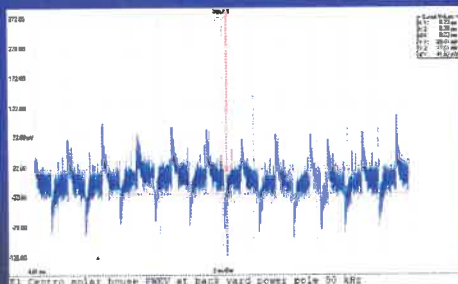
El Centro, California House with Solar Dr. Samuel Milham MD, MPH



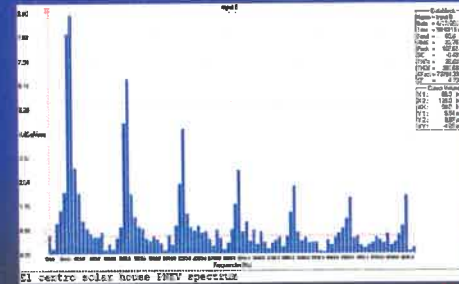
El Centro, California House with Solar Dr. Samuel Milham MD, MPH



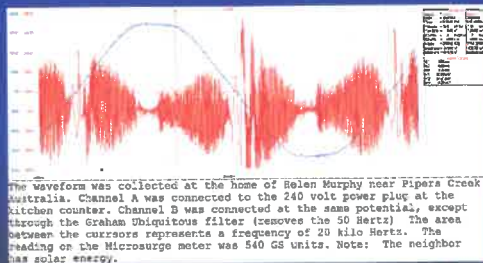
El Centro, California House with Solar Dr. Samuel Milham MD, MPH



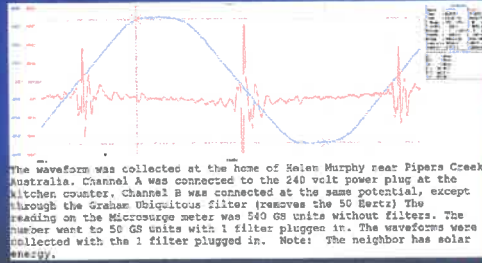
El Centro, California House with Solar Dr. Samuel Milham MD, MPH

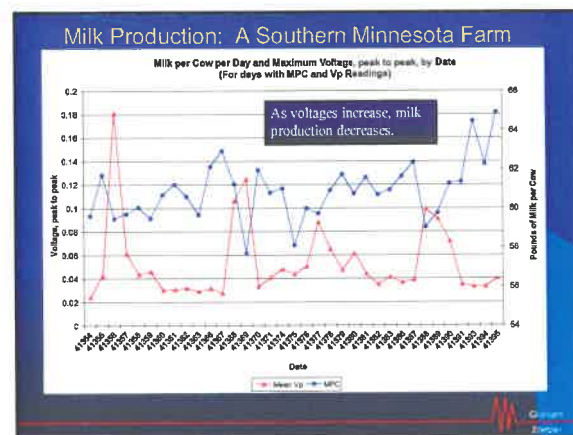
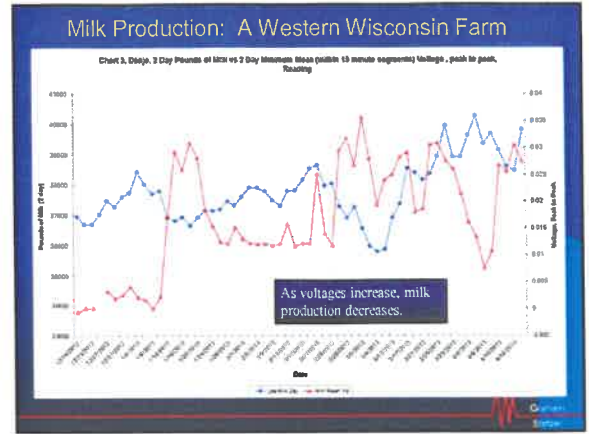
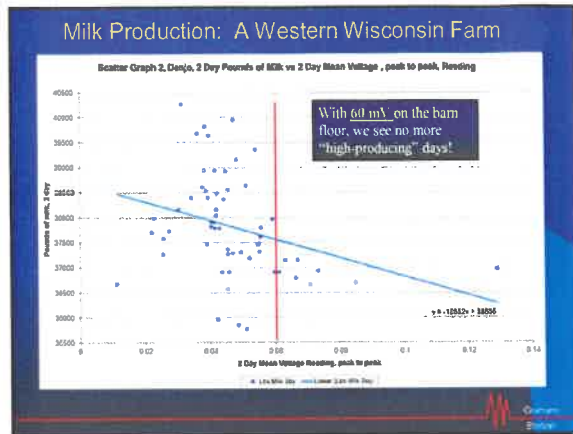


Pipers Creek, Australia The Neighboring Home Has Solar



Pipers Creek, Australia After 1 Stetzerizer Filter Installed in Client's Home





Minnesota Study

Final Report of the Science Advisors to the Minnesota Public Utilities Commission:

Research Findings and Recommendations Regarding Claims of Possible Effects of Currents in the Earth on Dairy Cow Health and Milk Production

July 31, 1990
Minnesota Public Utilities Commission
2175 Place East, Suite 350
St. Paul, Minnesota 55101-2147

"We have estimated that voltages as low as 0.002 volts could conceivably cause internal electric fields in the cow that are high enough to produce a physiological response"

Tingle Voltage

Ontario Hydro Power Quality Reference Guide, 3rd Edition

ELECTRICAL DISTURBANCES

Table 9.1 Power Line Disturbances

Disturbance	Effects on Animals	Human Health	Summary of Mitigation
Stray neutral to ground voltage	Fertility inconsistencies in farm animals, lowered milk production, unusual reactions of farm animals. For cows, uneven or negligible milking, nervousness, tail swishing, refusal of food or water	Tingle voltage is mainly a problem with farm animals, since many of them can feel voltages as low as 0.3V; this is one hundredth of what the average person can detect	Grounding, shielding, etc.

Symptoms of radio-wave sickness

Naval Medical Research Institute

Brain: Headaches, Dizziness, Nausea, Fatigue, Irritability, Depression, Anxiety, Insomnia, Memory Loss, etc.

Respiratory: Coughing, Wheezing, Shortness of Breath, etc.

Heart: Palpitations, Arrhythmias, etc.

Others: Skin rashes, Hair loss, etc.

Project #W12-524, 015-0004

Naval Medical Research Institute, Naval Medical Research and Development Command, 4001 ...

4 October 1977

Naval Medical Research Institute, Naval Medical Research and Development Command, 4001 ...

Symptoms of Radio Wave Sickness

Neurological: headaches, dizziness, nausea, difficulty concentrating, memory loss, irritability, depression, anxiety, insomnia, fatigue, weakness, tremors, muscle spasms, numbness, tingling, altered reflexes, muscle and joint pain, leg/foot pain, 'Flu-like' symptoms, fever. More severe reactions can include seizures, paralysis, psychosis, and stroke.

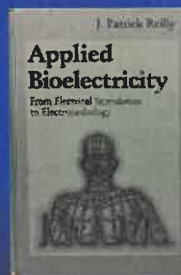
Cardiac: palpitations, arrhythmias, pain or pressure in the chest, low or high blood pressure, slow or fast heart rate, shortness of breath.

Respiratory: sinusitis, bronchitis, pneumonia, asthma.

Dermatological: skin rash, itching, burning, facial flushing.

Ophthalmologic: pain or burning in the eyes, pressure in/behind the eyes, deteriorating vision, floaters, cataracts.

Others: digestive problems; abdominal pain; enlarged thyroid; testicular/ovarian pain; dryness of lips, tongue, mouth, eyes; great thirst; dehydration; nosebleeds; internal bleeding; altered sugar metabolism; immune abnormalities; redistribution of metals within the body; hair loss; pain in the teeth; deteriorating fillings; impaired sense of smell; ringing in the ears." (Firstenberg, 7)



The smallest current having an observable effect (heart rhythm disturbances) occurs at 80 μA in humans (Reilly 1998).

Contact Current & Cancer

The Possible Role of Contact Current in Cancer Risk Associated With Residential Magnetic Fields

R. Kavec,* L. E. Zaffinella, J. P. Daigle, and K. L. Ebb

EPRI, Palo Alto, California

Enertech Consultants, Lenox, Massachusetts

Residential electrical wiring systems are a source of contact current, which is the current that flows through the body when a person touches a live wire.

... the absolute (as well as modest) level of contact current modeled (18 μA) produces average electric fields in tissue along its path that exceed 1 mV/m. At and above this level, the NIEHS Working Group [1998] accepts that biological effects relevant to cancer have been reported in "numerous well-programmed studies".

Exposure to a vertical electric field (100 V/m), a modest level of contact current (18 μA) leads to considerably greater induced electric fields (> 1 mV/m) averaged across tissue, such as bone marrow and heart. The correlation of VEC with magnetic fields in the model, combined with the dose estimates, lead us to conclude that VEC is a potentially important exposure with respect to childhood leukemia risks associated with residential magnetic fields. These findings, nevertheless, may not apply to residential wiring used in several European countries or to the Scandinavian studies conducted with populations exposed to magnetic fields from overhead transmission lines. Bioelectromagnetics 21:538-553, 2000.

EPRI Handbook (1995)



- In the "Handbook for the Assessment and Management of Magnetic Fields Caused by Distribution Lines" EPRI (Electrical Power Research Institute) states, "Furthermore, proximity to distribution lines has been associated with the risk of childhood cancer in three epidemiological studies."
- Copies of the paper bound book can be purchased from EPRI for \$25,000.00 each for non-members.

Hygienic, Clinical, and Epidemiological Analysis of Disturbances Induced by Radio Frequency EMF Exposure in Human Body (2000)

Clinical and physiological investigations of people highly exposed to electromagnetic fields

St. Petersburg, Russia

October 10-12, 2000

CNS and cardiovascular system pathology level is significantly higher in regulators and in persons previously exposed to EMF than that in the control group.



Medical Hypotheses (2001)

S. Milham, E. M. Ossiander

Historical evidence that residential electrification caused the emergence of the childhood leukemia peak

The authors conclude the childhood leukemia peak of common acute lymphoblastic leukemia (cALL) is attributable to residential electrification. 75% of childhood acute lymphoblastic leukemia and 60% of all childhood leukemia may be preventable.

© 2001 Elsevier B.V.

Abstract

By 1967, childhood leukemia and ALL had increased 10-fold since 1930. In the United States, the incidence of childhood leukemia and ALL has continued to rise, reaching a peak in 1990. The authors conclude that the childhood leukemia peak is attributable to residential electrification. 75% of childhood acute lymphoblastic leukemia and 60% of all childhood leukemia may be preventable.

California Health Department

AN EVALUATION OF THE POSSIBLE RISKS FROM ELECTRIC AND MAGNETIC FIELDS (EMFs) FROM POWER LINES, INTERNAL WIRES, ELECTRICAL OCCUPATIONS, AND APPLIANCES

Prepared by
Raymond Richard Hewitt, M.D., Dr.P.H.
Vincent DelPreto, Ph.D., GGS
Gerritine M. Lee, Ph.D.

“EMFs can cause some degree of increased risk of childhood leukemia, adult brain cancer, Lou Gehrig’s Disease, and miscarriage.”

Final Report June 2002

RADIATION BIOLOGY

Human cancer cells grow at a rate of 1600% and become more malignant.

Radiation Protection Dosimetry (2007)

LOW-FREQUENCY TRANSIENT ELECTRIC AND MAGNETIC FIELDS COUPLING TO CHILD BODY

Ozen, S. 2007. LOW-FREQUENCY TRANSIENT ELECTRIC AND MAGNETIC FIELDS COUPLING TO CHILD BODY. Radiation Protection Dosimetry (2007), pp: 1-6.

S. Ozen
Department of Electrical and Electronics Engineering, Engineering Faculty, Abdenia University, 87058 Antalya, Turkey

The results of this study show that the transient electric and magnetic fields would induce higher current density in the child body than power frequency fields with similar field strength.

IEEE-SA Press Release

IEEE TO DEVELOP STANDARDS LIMITING INSERTION OF HARMONICS INTO POWER GRID

April 25, 2011

- “Harmonic pollution is a growing problem caused by the widespread use of power supplies and other non-linear loads.”
- “It can result in power loss and equipment damage and it may also be related to environmental safety issues.”

“Electronic Smog: The Curse of the Mobile Phone Age”

Lower, Geoffrey. “Electronic Smog: The Curse of the Mobile Phone Age.” *The Independent* 7 May 2006.

“...that our civilization is in a state of emergency. The conditions exist in the world that could harm up to 3 in every 100 people who are affected by it.”

“...the image of a child in a mobile phone, our civilization, is giving children cancer, causing a life-threatening condition that is making the people to become allergic to electricity, leading to nausea, pain, dizziness, depression and difficulties in sleeping and concentrating...”

Solutions

Charles DeNardo, Chief Electrical Engineer for We Energies

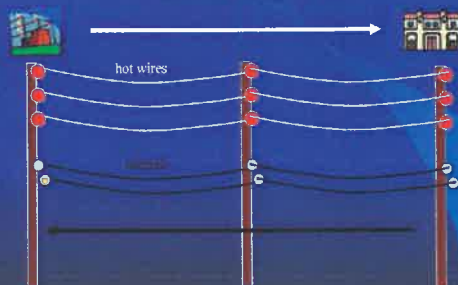
testified in the 1995 PSC Docket 05-EI-108

"Fortunately, there are proven and relatively inexpensive techniques for addressing any type of ground current transients, including those that are intermittent."

Thicker neutral wire "Oversized Neutral"



Two neutral wires "5-wire distribution system"



Five-Wire Solution

Five-Wire Distribution System Demonstration Project

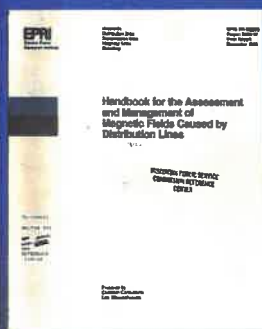
Team: A. Stout, Senior Member, IEEE, James R. Stewart, Fellow, IEEE, David R. Smith, Fellow, IEEE, James O'Brien, Member, IEEE, and Kenneth Hampton

Manuscript received August 14, 2000; revised October 9, 2001. This work was sponsored by the New York State Electric and Gas Corporation, New York State Energy Research and Development Agency, Empire State Electric Energy Research Corporation, and EPRI.

IV. STRAY VOLTAGES
During the monitoring periods, the stray voltage in the five-wire configuration was about 40% lower than the four-wire configuration as shown in Table I.

Spot measurements at various locations were done for magnetic field during four-wire and five-wire operation. During five-wire operation, the magnetic fields were generally lower. At most locations, the magnetic fields were generally 10% to 30% lower than at the same locations during four-wire operation.

EPRI (1995)



6.5 Five-Wire Primary Lines

"A method that practically eliminates ground currents associated with primary distribution lines and still maintains the advantages of a four-wire multi-grounded system, is the five-wire system"

PQ TechWatch – EPRI (2016)

PQ TechWatch: Update on Harmonics Standards

Product ID: PQ20160001
Date Published: Sep 18, 2016
Pages: 78
Series Name: PQ2016 Update on Harmonics Standards and the Grid
Document Type: Technical Report

PRICE: \$5,000 (US Dollars)

Abstract
"Harmonic standards must be reevaluated to maintain and promote future system compatibility in the integrated grid."

IEEE 519-1992
Institute of Electrical and Electronics Engineers

IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

Sponsors

12. Recommended Practices for Utilities (page 83)

1. Perform harmonic measurements at selected points within the utility circuit, including the PCC, and look for consumers with converters operating with current distortion beyond the limits. If identified, such consumers should be asked to keep the harmonic distortion within the recommended limits by installing filters, by reducing harmonic generation, or through other means.
2. Install filters to control the harmonics.
3. Install a new feeder. This is effective in stiffening the source and isolating the harmonic problems. However, it is not always economically feasible.

Cooperative Effort

1. The solution to this problem requires a cooperative effort.
2. Utilities need to update their outdated distribution systems to meet today's technological loads.
3. Consumers (including Wind/Solar generation operators) need to reduce the amount of high frequencies they are putting on electrical wires.
4. Existing standards and rules need to be enforced!

Conclusions

Position on Renewable Energy

- I am not anti-solar or anti-wind
- However, as currently designed and implemented, these systems cannot comply with applicable Standards, and are unsafe for human and animal health
- Issues of high frequency transients and harmonics introduced into the electric grid and the ground must be properly addressed
- Existing standards must be enforced

Questions

???