Power Influence on Telecom Systems

EE530 Power Quality
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Introduction

- Power system harmonics have a detrimental effect on ***power system*** operation: power quality, efficiency of machine operation, premature failure of components, etc.
- Not many people are aware of the detrimental effect on ***telecom systems***: noise, failures, service interruptions, etc.
- Often power quality issues affect telecom systems before power system people are aware that there is a problem
- This talk will focus on ***power influence*** - the effect of utility system harmonics on telecom systems

Outline

- **Overview of power influence due to harmonics**
  - How it works
  - How it's measured
  - Standards
- Noise mitigation on the telecom system
  - Shielding
  - Twisted pairs
  - Noise filtering devices
- Real world noise case

Why Does Interference Occur?

- Power systems transmit very high energy
  - MW, kV, kA
- Telecom systems transmit much smaller signals
  - mW, μW, (lowest audible noise is 1 pW = 10^{-12} W)
- MW (10^{6} W) to μW (10^{-6} W) – ratio of 10^{12}
- Although telecom systems are designed with interference in mind and can reject a lot of it, small amounts of spillage of MW can still have a significant effect
- Power and telecom cables are often close together, and run parallel for long distances (utility side: many kilometers), which means electromagnetic coupling

Aerial Joint Use

Cable TV

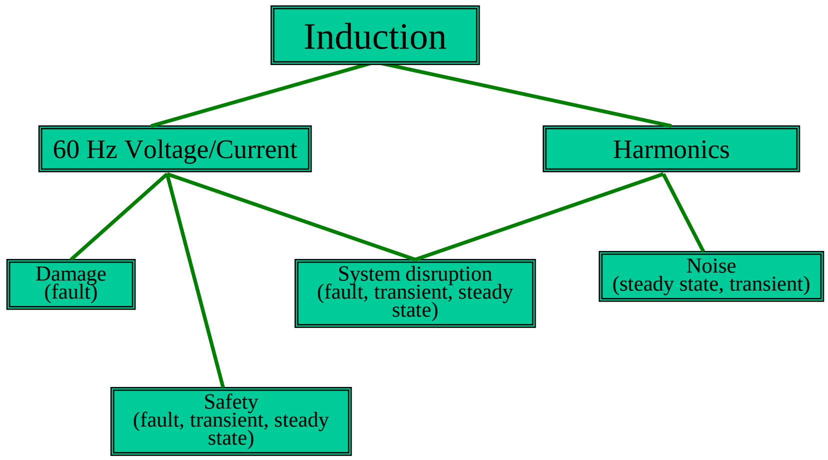
Telephone cable

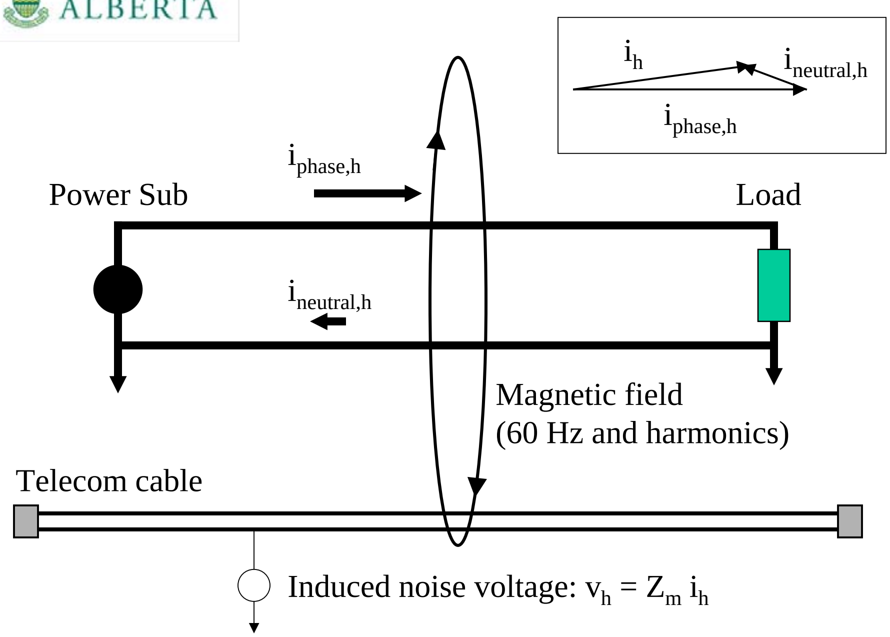
Primary power (13kV)

Secondary power (120V/240V)

Buried Telephone Cable

Types of Induction Problems





Mutual Impedance

- Carson's Equation (Bell System Technical Journal, 1926)

$$Z_m = \frac{j\omega\mu_0}{2\pi}\left[\ln\frac{d_{12}^{'}}{d_{12}} - 2j\int_0^\infty \left[\sqrt{(u^2+j)} - u\right] e^{-u\alpha(h_1+h_2)}\cos(u\alpha s)du\right]$$

- Exact expression, derived from electromagnetic field theory, but too complicated in practice

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Mutual Impedance

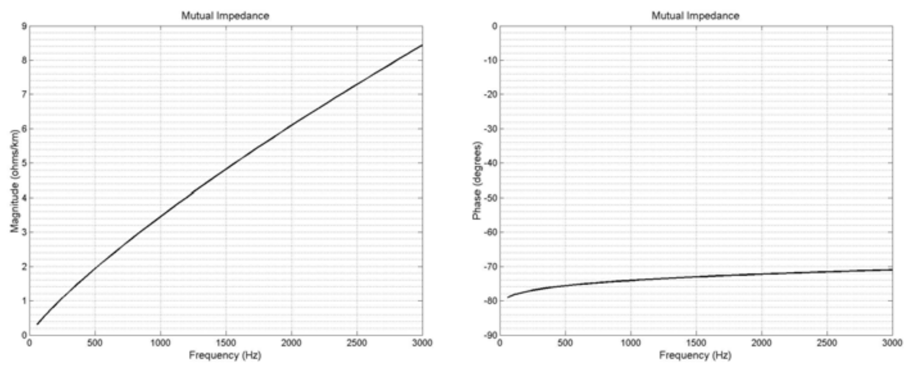
- Simplified approximation of Carson's Equation (Parker, Bell Labs, 1980 and IEEE Std 367-1996)

$$Z_m = R_m + jX_m = \frac{j\omega\mu_0}{2\pi}\left[\ln\frac{D_1}{D_0} - \frac{1}{12}\left(\frac{2}{\gamma D_1}\right)^4\right](\Omega/km)$$

$$D_0 = \sqrt{s^2 + (h_1 - h_2)^2} \qquad D_1 = \sqrt{s^2 + \left(h_1 + h_2 + \frac{2}{\gamma}\right)^2}$$

$$\gamma = \sqrt{j\omega\mu_0\sigma}$$

Mutual Impedance



100 ohm*m soil resistivity, 7.62 m height difference, 13.2 m separation

How Much Interference?

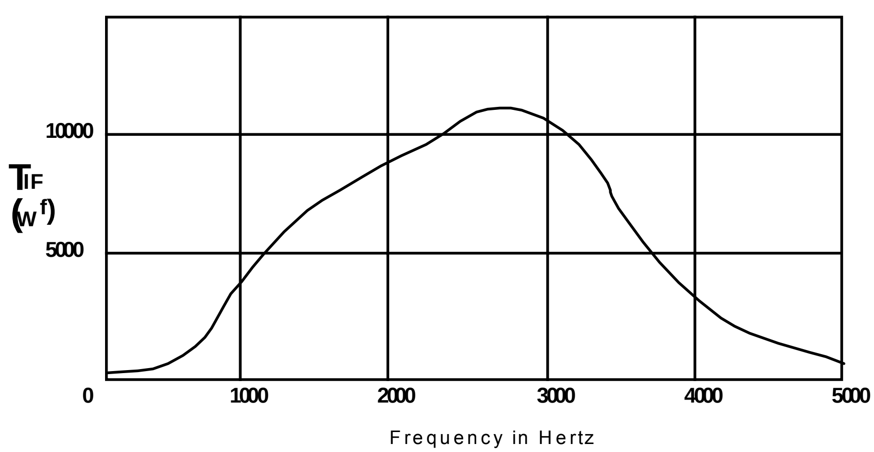
The severity of a power induction problem depends on:

- **Influence** – “How bad is the power line?”
  - Conditions on the power line: balance, harmonic content, earth return current, phases, grounding, impedance of neutral
  - Limits defined in ECUC, IEEE 519, IEEE 776, IEC 61000, CSA C22.3 No. 3-98, CEA Electrical Coordination
- **Susceptibility** – “How bad is the phone system?”
  - Conditions on the phone system: cable balance, sheath integrity, equipment, grounding
  - Limits defined in IEEE, CSA C22.3 No. 3-98, CEA Electrical Coordination, Telcordia specs
- **Coupling** – “Geometry”
  - Separation, length of parallel, earth resistivity

TIF Quantifies the Influence

- Telephone Interference Factor (TIF) is a key quantity used in the measure of a power influence problem
- Each harmonic is assigned a relative interfering weight W_f (or W_h) which is determined by three factors
  - The bandpass filter used in telephone circuits. The intelligible portion of speech is approximately 300 Hz to 3000 Hz, so the remaining is filtered out.
  - “Annoyance” factor: how the human ear responds to noise at different frequencies. This varies from person to person, so an average value is used.
  - Frequency: $v_f = Z_m(f) \cdot i_f$

Telephone Influence Factor Curve



TIF Weighting Factors

h	Freq (Hz)	Wf	h	Freq (Hz)	Wf	h	Freq (Hz)	Wf
1	60	.5	29	1740	7320	57*	3420	7470
3*	180	30	31	1860	7820	59	3540	6730
5	300	225	33*	1980	8330	61	3660	6130
7	420	650	35	2100	8830	63*	3780	5080
9*	540	1320	37	2220	9330	65	3900	4400
11	660	2260	39*	2340	9840	67	4020	3700
13	780	3360	41	2460	10340	69*	4140	3210
15*	900	4350	43	2580	10600	71	4260	2750
17	1020	5100	45*	2700	10480	73	4380	2190
19	1140	5630	47	2820	10210	75*	4500	1830
21*	1260	6050	49	2940	9820			
23	1380	6370	51*	3060	9230			
25	1500	6680	53	3180	8740			
27*	1620	6970	55	3300	8090			

* 0 Sequence

I*T and kV*T Products

- Analysis of individual harmonics is important, but it is also useful to define an aggregate quantity to sum it all up:

$$I \cdot T = \sqrt{\sum_h (i_h W_h)^2} \qquad kV \cdot T = \sqrt{\sum_h (v_h W_h)^2}$$

- Units: weighted amperes or weighted kilovolts
- CSA limit on *probe wire* I*T is 500 A

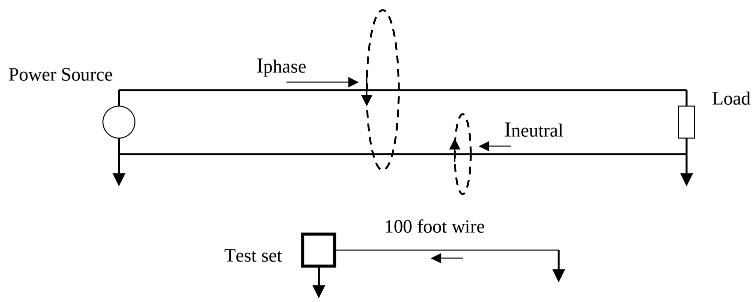
Different I*T Measurements

- I*T is most commonly used, and has a few different interpretations depending on which document you read (some are not very clear)
  - Balanced I*T: includes only positive and negative sequence harmonics
  - Unbalanced I*T: includes only zero sequence harmonics
  - Residual I*T: includes all harmonics, vector summed over the three phases (some of these currents may flow on the neutral)
  - Ground return I*T: includes all harmonics, vector summed over the three phases and the neutral
  - Probe wire I*T: the total harmonic content as seen by a 100 foot test probe wire placed parallel to the power line

Different I*T Measurements

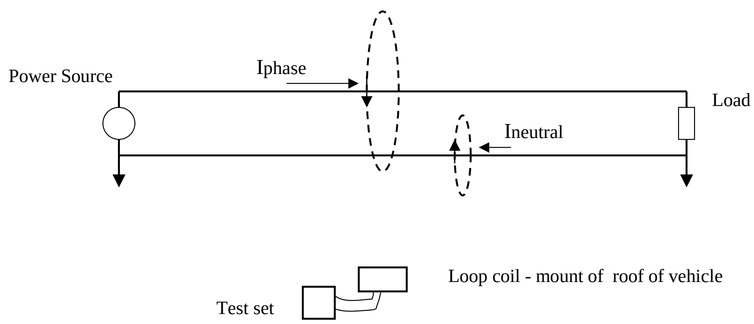
- Balanced, unbalanced and residual I*T are measured on the power system, and can be done on either the primary or secondary side (need to consider turns ratio of transformer)
- Probe wire I*T is the best representation of what will be induced on a parallel telephone cable
- Ground return I*T on the primary can be related to probe wire I*T
- If there is no neutral on the primary (rural power systems) residual and ground return I*T are the same

Probe Wire Measurement



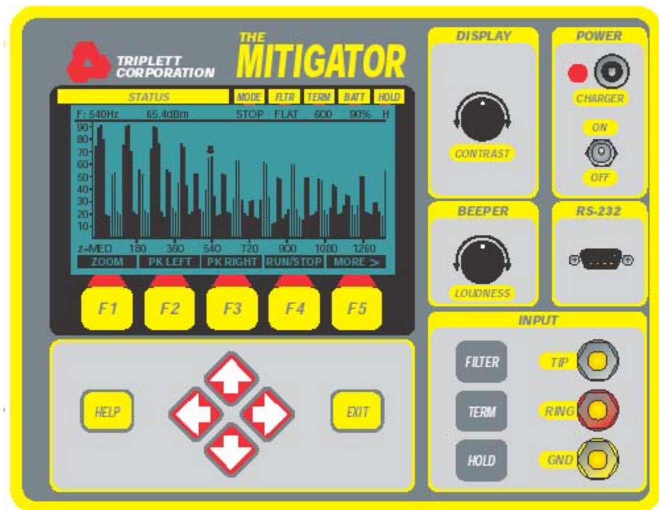
Test set measures individual harmonics and gives an I*T reading

Loop Coil Measurement



Test set measures individual harmonics - relative strength
Can track a single harmonic with an audible Geiger mode

Tools


TRIPLETT CORPORATION
THE MITIGATOR
STATUS
MODE
FLTR
TERM
BATT
HOLD
F: 540Hz
65.4dBm
STOP
FLAT
600
90%
H
ZOOM
PK LEFT
PK RIGHT
RUN/STOP
MORE >
F1
F2
F3
F4
F5
HELP
EXIT
DISPLAY
CONTRAST
POWER
CHARGER
ON
OFF
BEEPER
LOUDNESS
RS-232
INPUT
FILTER
TERM
HOLD
TIP
RING
GND

Tools


Ground pegs
Loop coil
100 ft. wire

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Standards and Legislation

- Inductive Coordination
  - CSA C22.3 No. 3 Electrical Coordination
  - CEA Electrical Coordination Guide
  - IEEE 776-1992 Recommended Practice for Inductive Coordination of Electric Supply and Communication Lines
  - IEEE 1137-1991 Guide for the Implementation for Inductive Coordination Mitigation Techniques
- Power System
  - IEEE 519-1992 Recommended Practices and Requirements for Harmonic Control in Electric Power Systems
  - IEEE 367-1996 Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage From a Power Fault
  - IEC 61000 Electromagnetic Compatibility
  - Alberta Electrical and Communication Utility Code
- Telecom System
  - IEEE 820-1984 Standard Telephone Loop Performance Characteristics
  - IEEE 455-1985 Standard Test Procedure for Measuring Longitudinal Balance of ...
  - Telcordia Practices
  - Alberta Electrical and Communication Utility Code

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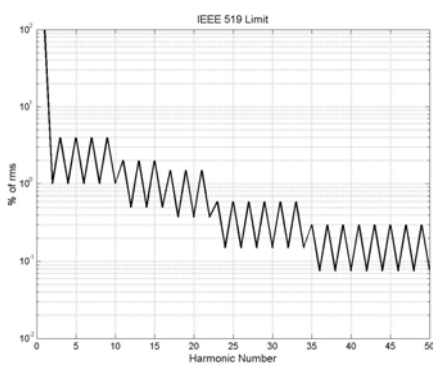
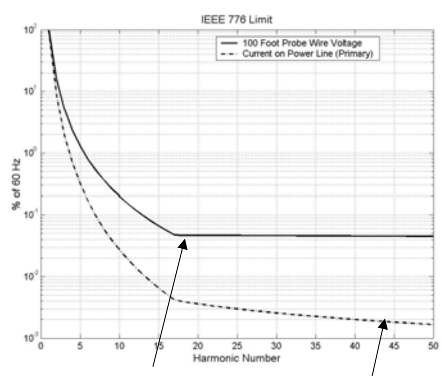
Individual Harmonic Limits





Measured directly on power conductors at load
(I_{sc}/I_L<20, 120V through 69kV)

Voltage measured on 100 ft. probe wire interface placed 50 ft. from power line primary
(limit for 4.752 km to 15.240 km parallel)

Current on primary: calculated using mutual impedance

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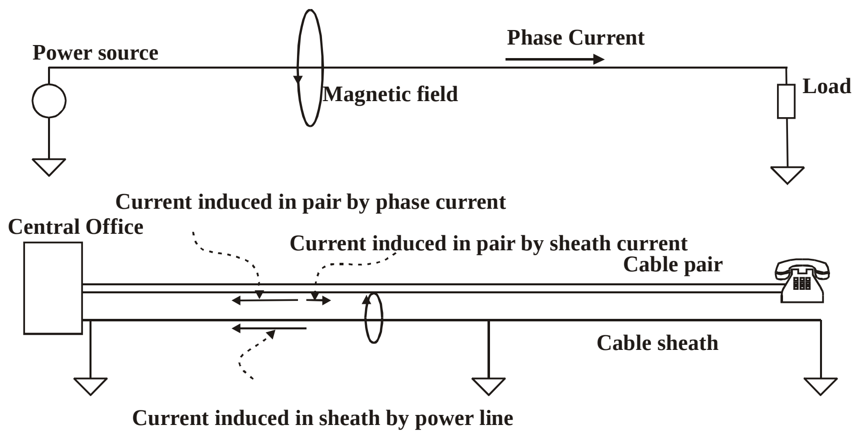
- **Noise mitigation on the telecom system**
  - Shielding
  - Twisted pairs
  - Noise filtering devices
- Real world noise case

Shielding

- Many think that because the telecom wires are encased inside a grounded metallic shield that the wires are shielded completely from noise - not true!
- Encasement inside a metallic structure forms a "Faraday cage" which blocks ***electric fields***
- Power influence due to induction is a ***magnetic field*** phenomenon
- A Faraday cage does nothing to block magnetic fields
- Magnetic shielding occurs due to a different phenomenon

Magnetic Shielding



Magnetic Shielding

- Current induced in grounded shield induces a longitudinal current in the cable pair which reduces the current induced by the power line
- Magnetic shielding occurs due to any parallel grounded conductor
- Effectiveness of shielding depends on frequency, resistance of conductor, resistance of grounds, size of cable, length of cable, and phases of individual harmonic components
- There is almost no shielding at 60 Hz, shielding increases with frequency

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Twisted Pair

- A significant reduction in noise is accomplished by using twisted pair cable
- Impedances of the two conductors of a pair (called tip and ring) must be very close (limited by practical manufacturing processes) - ***balanced pair***
- Any equipment connected to the pair must also be well balanced otherwise the noise immunity is ruined

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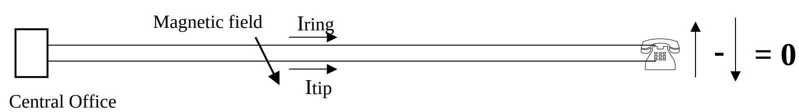
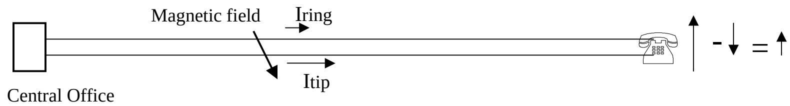
Ideal Cable



- If the impedances of the two conductors of a pair are exactly the same throughout the cable length, then the currents (called ***longitudinal currents***) induced will be exactly the same
- The longitudinal currents will then cancel out in the terminating circuit, and there will be no noise regardless of the amount of induction present

Real World Cable



- The impedances of the two conductors are never exactly the same throughout the cable length, so the longitudinal currents are not the same
- The longitudinal currents do not cancel, resulting in a ***differential noise current*** which will affect the quality of service

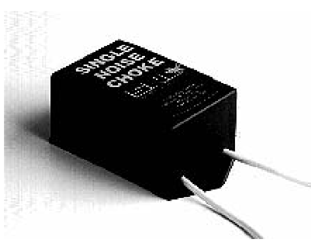
Cable Balance

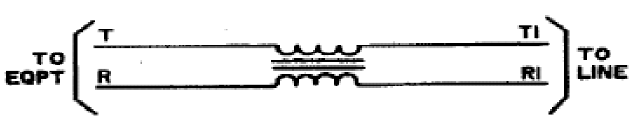
- Standards say balance should be greater than 60 dB $\Rightarrow$ reduce induced voltage or current by a factor of 1000 or more
- Impedance difference: ΔR, $j2\pi f \Delta L$, $1/(j2\pi f)(1/C_T - 1/C_R)$
- Balance is frequency dependent: ability to reject noise gets worse with frequency

Noise Filtering Devices

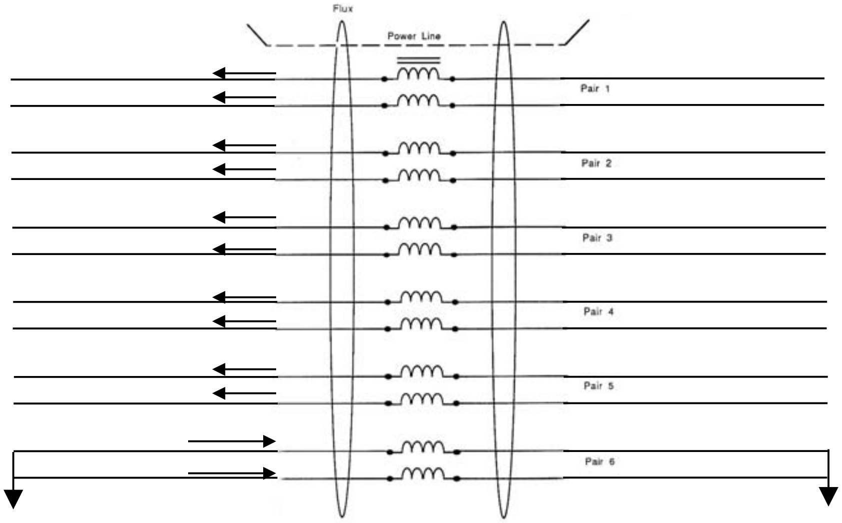
- Noise choke
- Induction neutralizing transformer (INT) or induction control transformer (ICT)
- Harmonic drainage reactor (HDR)
- Transformer excited network (TEN)
- Single Noise Interfering Exterminator (SNIX)

Noise Choke





Induction Neutralizing Transformer



HDR and TEN

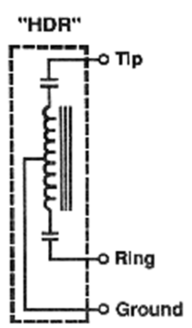


Figure 2: Harmonic Drainage Reactor (HDR)

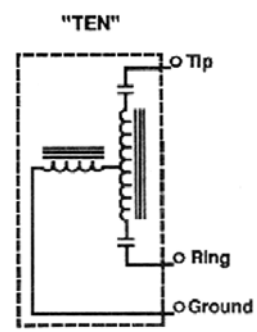


Figure 3: Transformer Exciting Network (TEN)

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SNIX and SuperSNIX

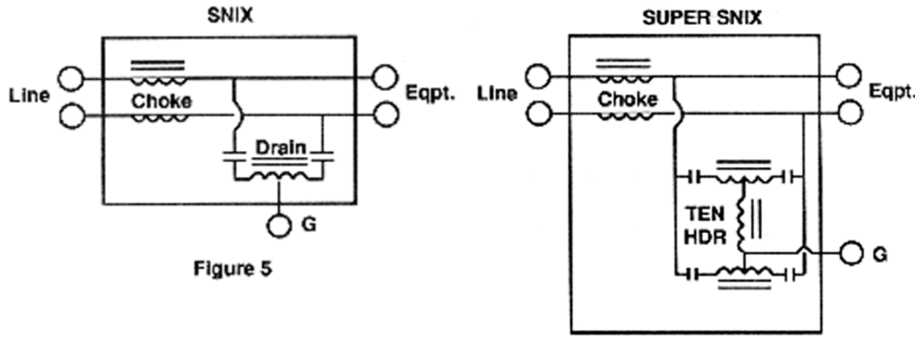

Figure 5

Figure 6

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Installation of Filtering Devices

- Noise Choke and INT
  - Theoretical optimum placement is the electrical centre of the telecom/power parallel
  - In practice, need to experiment and measure resulting noise reduction
- HDR and TEN
  - Usually placed at one side or both sides of parallel
  - Sometimes used in conjunction with noise choke or INT
- SNIX
  - Usually placed at telecom customer's location or telephone switching office

Effectiveness of Filtering

- Can reduce noise by 5 to 20 dB
- Effectiveness depends on harmonic flow, which can change as power system changes
- Choice of location is fairly critical
  - best location found experimentally
  - best location changes with system changes
- Most effective at lower harmonics, less effective at higher harmonics
- Less effective as the I*T increases

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  - Noise filtering devices
- **Real world noise case**
  - 1500 HP, 18 pulse adjustable speed drive

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18 Pulse Adjustable Speed Drive

Condition (Target)	I*T (<500)	Ng (dBrnc) (<80)	Nm (dBrnc) (<20)	Balance (dB) (>60)
ASD full speed, CB on	8448	101	41	60
ASD full speed, CB off	10514	101.3	46.7	54.5
ASD low speed, CB off	19600	104.1	49.8	54.3
ASD low speed, CB on	12218	99.5	46.3	53.3
ASD down, CB off	1342	84.4	4.7	79.7

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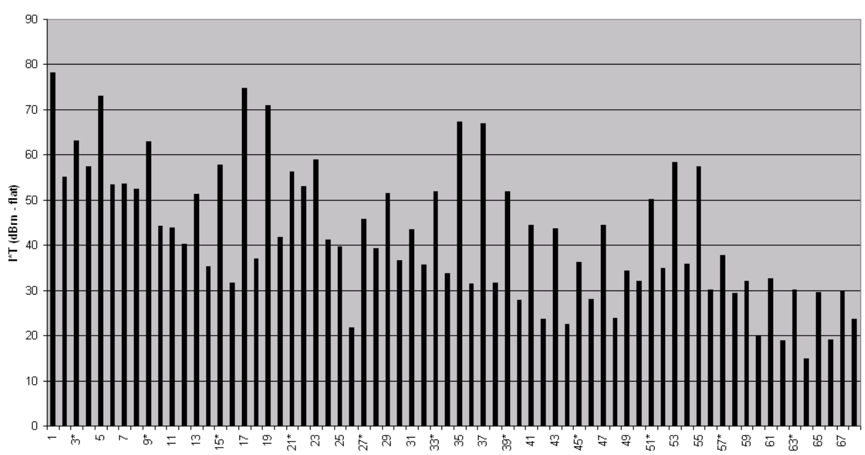
Probe Wire - Drive On



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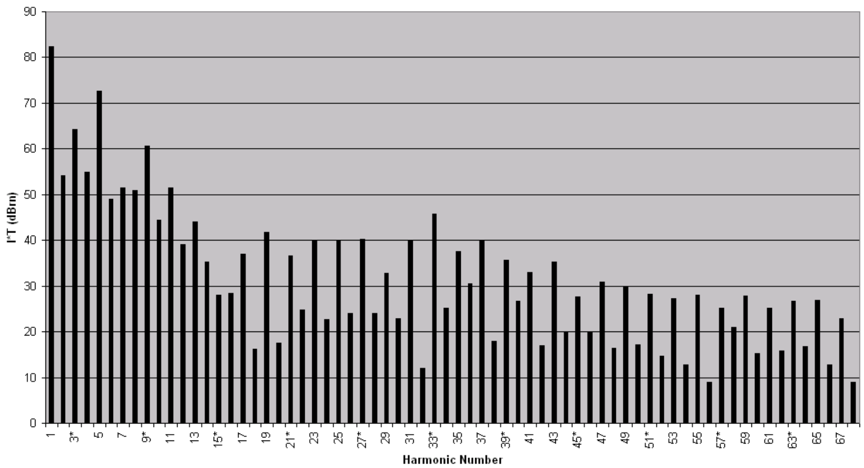
Probe Wire - Drive Off



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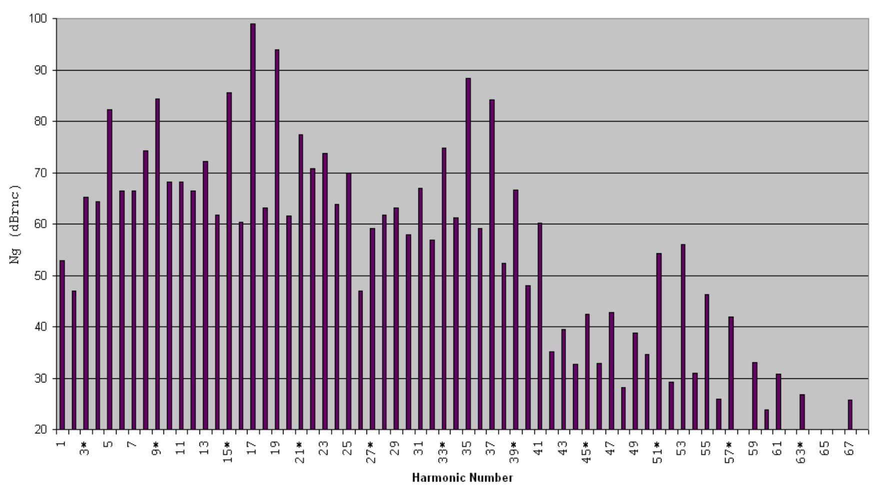
Noise - Drive On



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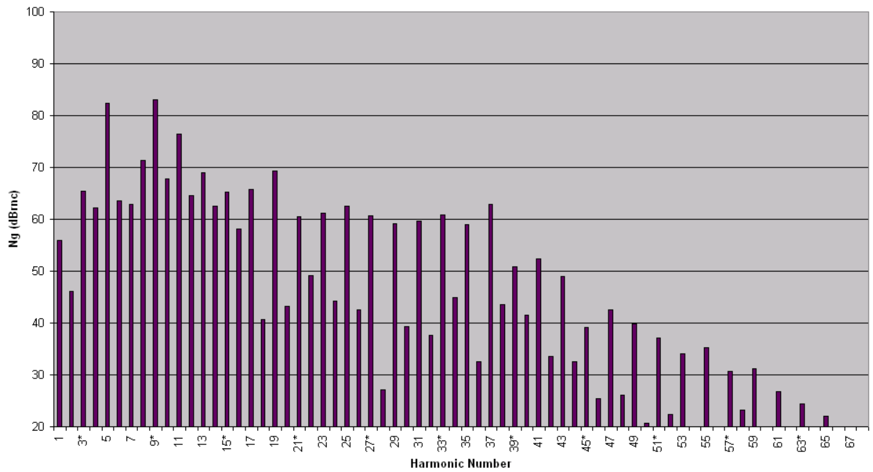
Noise - Drive Off



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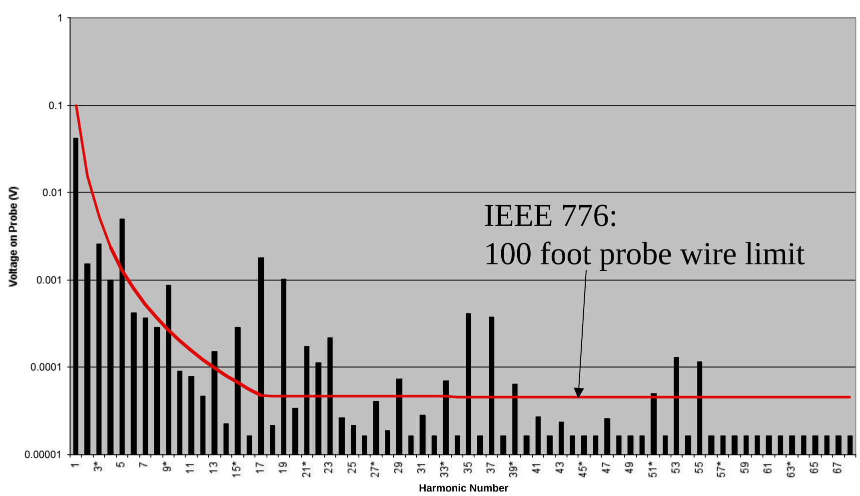
Probe Wire



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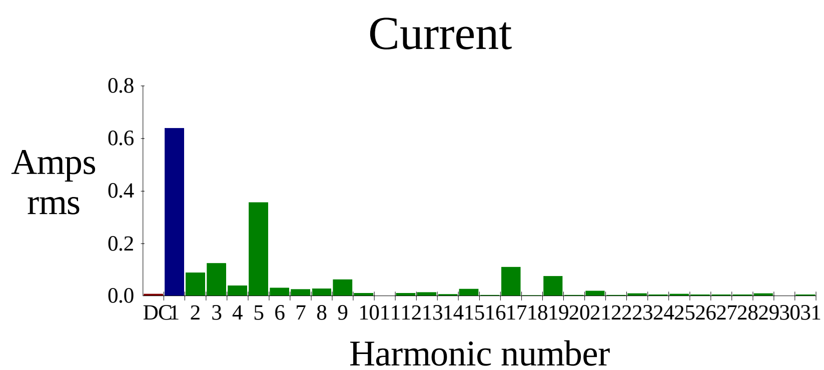
Power System Measurements



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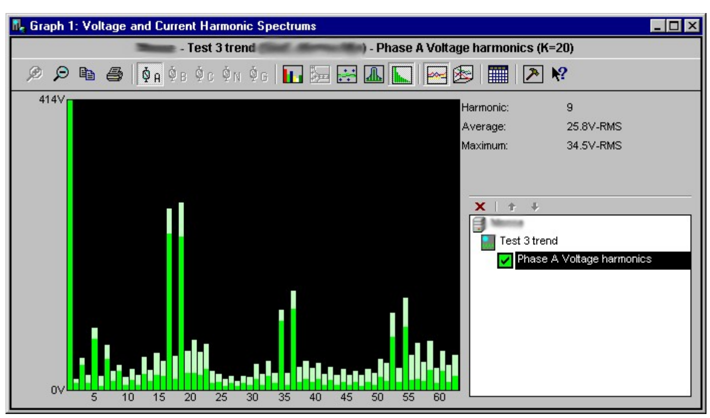
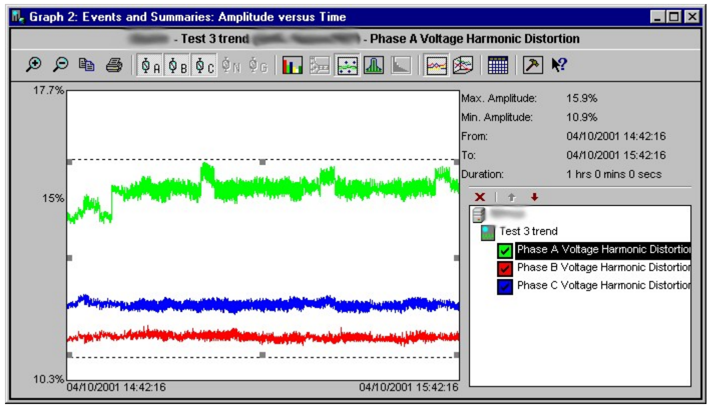


Voltage THD



Final Remarks

- Harmonics, especially high frequency harmonics generated by adjustable speed drives, can have a serious impact on telecom systems
- Solving inductive interference problems requires the application of appropriate measurement techniques and the correct standards (IEEE 519 is not sufficient)
- Cooperation between telecom company, power supplier, and power consumer is key in determining the best overall solution, considering costs and effectiveness of potential solutions
- Each company (telecom, power supplier, power consumer) must do its part to minimize impact