Harmonic Field Measurements, Analysis, and Filter Design Studies

GENERAL

With the increased use of harmonic producing equipment, such as AC/DC drives, arc furnaces and welders, and various electronic equipment, there is a growing concern about the overall level of power quality on industrial, commercial and utility power systems. The following areas are related particularly to harmonics:

- Excessive amounts of harmonics can cause equipment overheating, insulation degradation, equipment misoperation and/or premature failure. Capacitors, transformers, power cables, motors/generators, electronic equipment, static power converters, metering, switchgear/relays and telephone circuitry can be affected.
- The application of shunt capacitor banks for power factor correction can lead to resonant conditions that could amplify existing harmonics and cause capacitor failures and fuse nuisance operations.
- Meeting the IEEE Standard 519 guidelines on harmonic currents injected by loads (industrial and commercial plants), and the resulting harmonic voltages on utility supply systems may require the design and installation of harmonic filters.
- Industrial and commercial plants and electric utilities need to know existing harmonic levels prior to system expansion and/or change for proper design of harmonic suppression methods.

The Systems Engineering Group at Cooper Power Systems offers a single source solution for harmonic and power factor related problems. The group performs harmonic measurements with specialized test equipment, supplies harmonic measurement equipment, performs harmonic analysis studies, develops filter bank designs and specifications, develops and maintains harmonic analysis software and conducts harmonic training workshops.

The Cooper Power Systems Greenwood, South Carolina plant manufactures power capacitors and packages harmonic suppression filters for medium and high voltage systems.

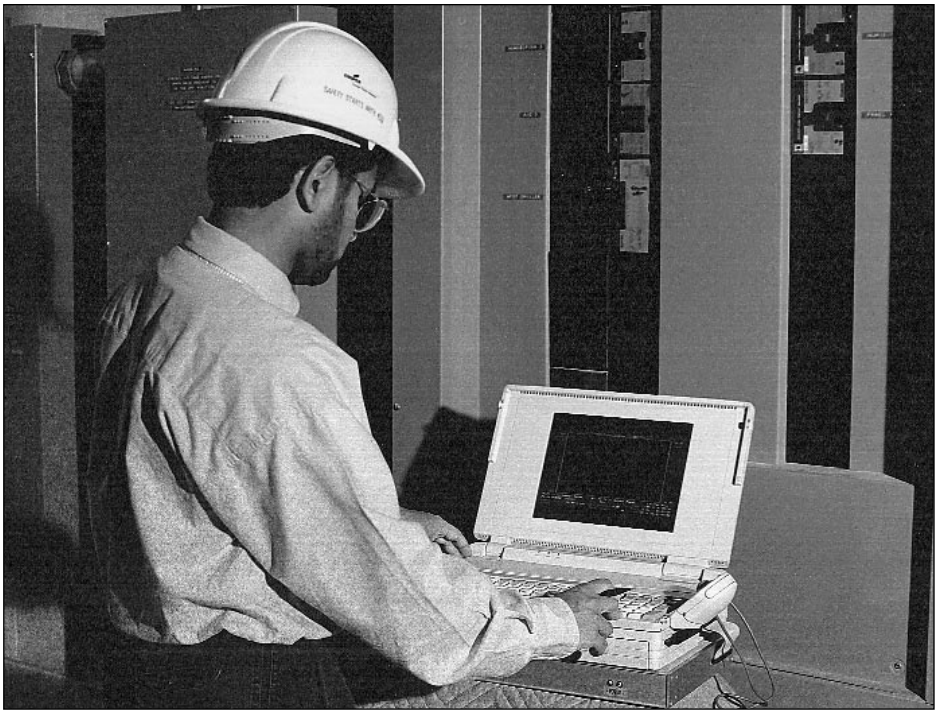

Figure 1.
Experienced engineers using sophisticated measurement equipment conduct on-site harmonic measurements.

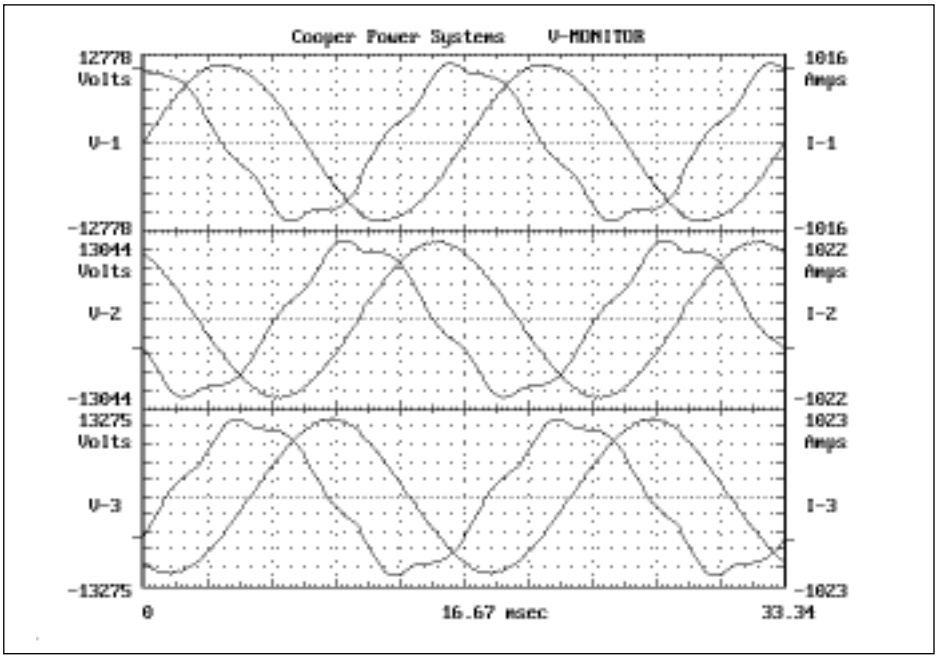

Figure 2.
Harmonic filter bank current and bus voltage monitored during a field measurement using Cooper Power Systems' V-MONITOR™ II system, a powerful tool for performing on-site harmonic measurements.

Features and Detailed Description

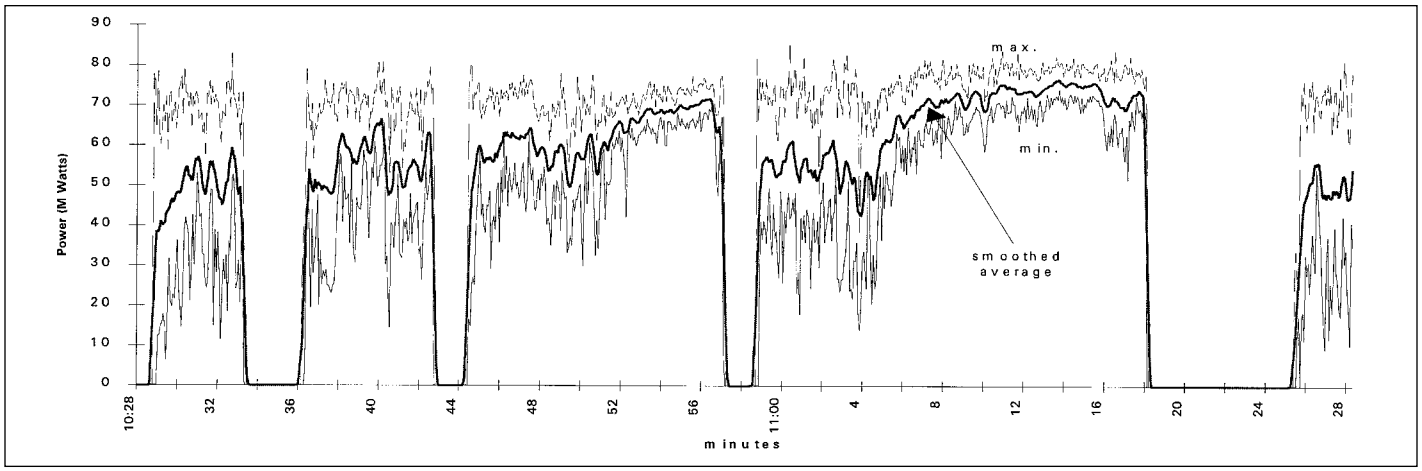

Figure 3.
Arc furnace power (total MW) vs. time, captured from a field test at a steel manufacturing facility using Cooper Power Systems' V-MONITOR II system.

APPLICATIONS

- Determine the cause of harmonic related equipment misoperations or failures.
- Monitor harmonic levels during extreme system conditions such as transformer energization, furnace arcing, peak harmonic loading conditions, etc., for rating of filter equipment.
- Design and installation of power factor correction capacitor/filter banks for power factor improvement and harmonic suppression.
- Monitor harmonics for commissioning of new harmonic filters, arc furnace systems, verification of harmonic suppression methods, etc.
- Perform plant/load surveys to monitor harmonic levels (THDs, harmonics from 2nd through 49th for currents and voltages), power levels (MW, Mvar and MVA) and power factors.
- System analysis studies to predict future harmonic levels when new equipment is installed or harmonic loads are relocated.
- Ensure compliance with IEEE Standard 519 limits for voltage and current.
- Monitor non-integer type harmonics in arc furnace installations.
- Measure K-Factors for transformers serving non-linear loads.

ADVANTAGES

- Equipment repair expenses and costs associated with lost production due to equipment failures can be reduced or eliminated.

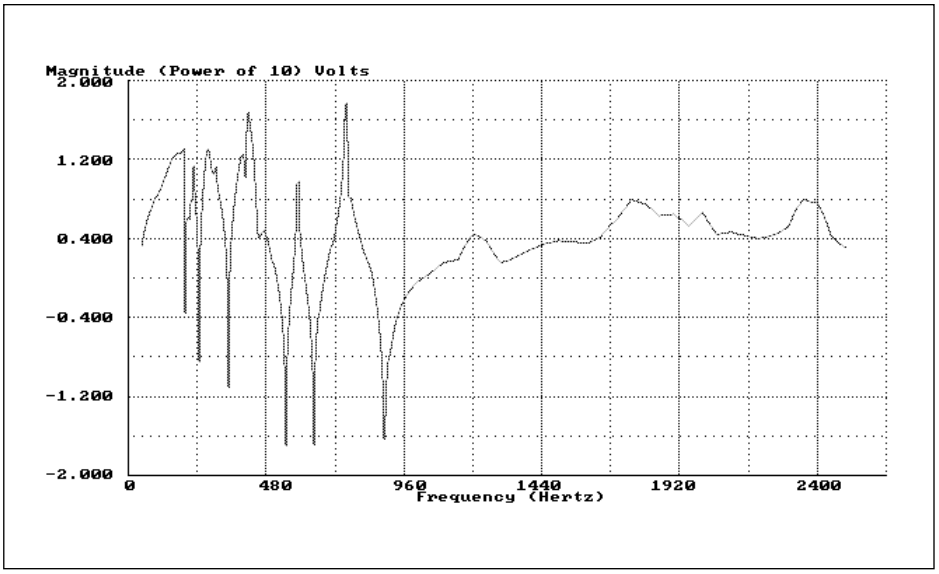

Figure 4.
Frequency scan plot of an industrial system with multiple harmonic filters, modeled using the Cooper Power Systems' V-HARM™ program.

- Engineers and equipment can be on site within 24 hours.
- Experienced engineers with advanced degrees perform field tests and analysis studies, working closely with site personnel to meet specific needs and requirements.
- Monitoring equipment used (V-MONITOR™ II) is especially designed to meet the needs of harmonic studies.
- All test equipment, adaptable for indoor and outdoor applications, is provided by Cooper Power Systems, including CTs, relay test plugs, connection cables, etc.
- Captured data can be easily used with commercially available software such as Microsoft® EXCEL and MATLAB® for customized analysis.
- Post-test analysis can be performed with advanced computer models and techniques to analyze unusual conditions.
- Overnight unattended monitoring is available as needed.
- Comprehensive bound test reports with field captured data (graphics

and printout tables) are produced summarizing study results.
- Monitoring equipment is connected without load shutdowns to avoid process disruptions.
- Harmonic filters can be designed, installed and field tested for proper operation and harmonic mitigation to meet operating objectives such as power factor and IEEE Standard 519 compliance.
- The industry's leading software package, the V-HARM™ program developed by Systems Engineering, is used for all studies.
- Precise harmonic filter specifications are developed for equipment manufacturers (reactors and capacitors).
- Comprehensive Thomas A. Edison Technical Center support is available for analytical and electrical testing and services to find complete solutions.
- All required harmonic filter equipment can be supplied by the Cooper Power Systems capacitor plant in Greenwood, South Carolina for medium and high voltage systems, to provide a complete package of harmonic equipment, filter design and installation.

SERVICES FOR INDUSTRIAL AND COMMERCIAL FACILITIES

The Systems Engineering Group has been performing harmonic tests and analysis for over 20 years for a wide variety of industries such as iron and steel, chemical, pulp and paper, mining, manufacturing, rubber and plastics, glass, and cement. Studies for commercial facilities include hospitals, telephone centers and office buildings. Power factor improvement and harmonic filter design and installation have been the most common types of studies. Postmortem studies, performed after unexplained equipment misoperations and/or failures, have also been conducted. Due to increasing awareness of power quality issues, plant surveys are becoming more common.

SERVICES FOR UTILITIES

Measurement of background harmonics, design of harmonic filters for HVDC systems, design of harmonic filters for SVC systems, and proper placement of distribution shunt capacitors to avoid harmonic amplification problems represent the types of studies performed for electric utilities.

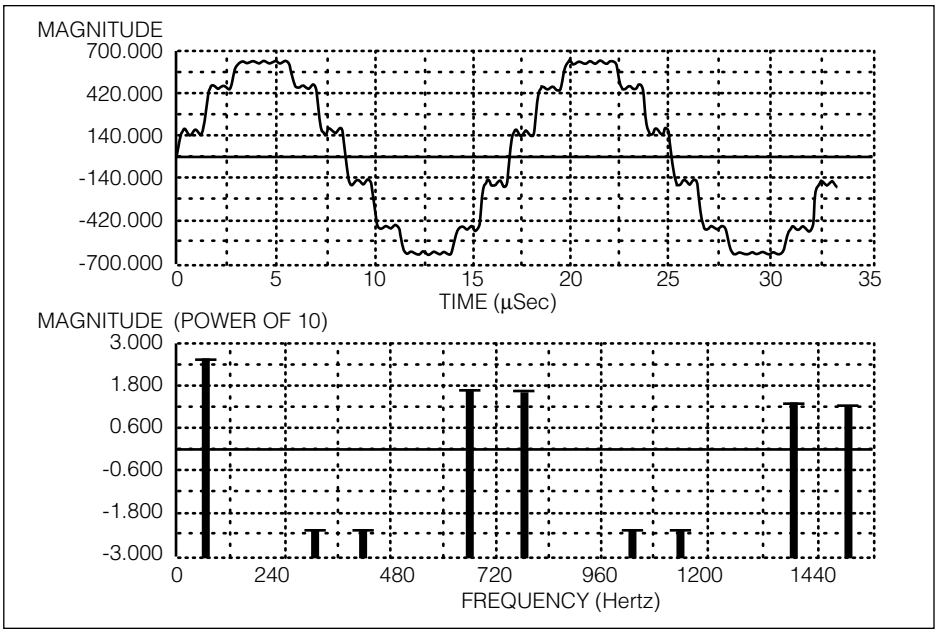

Figure 5.
Twelve-pulse converter current simulated with V-HARM program.

HARMONIC MEASUREMENTS

On-site harmonic measurements provide data needed to verify digital models for system analysis and the design of harmonic filters or other harmonic mitigation methods. Sources of harmonics can be identified. Background levels of harmonic distortion can be measured. System resonances and tuned frequencies of existing harmonic filters can be identified. Non-integer harmonics can also be precisely measured.

Measurements are done with customized equipment. The Cooper Power Systems' V-MONITOR II, a six channel harmonics monitor, is used to acquire, display, store and analyze harmonic data. Three-phase voltage and current harmonics, real, reactive and apparent powers, and power factors are measured and stored. Harmonics through the 49th, total harmonic distortion (THD), probability density functions (PDF), telephone interference factors (TIF), time trends, waveform plots of voltage and current for all three phases, and transformer K-Factors are measured. For measurements where harmonics higher than the 49th are needed, customized capacitive voltage dividers with a multi-channel data acquisition system are used. These measurements can be a valuable future reference for new equipment installations.

Harmonics are usually a steady-state phenomena. They are present whenever a non-linear load is operating. The loading level affects the harmonics. Pseudo-harmonic type loads are sometimes needed, such as the energization of a transformer to analyze the harmonic content of the inrush current waveform. The amount of data gathered is a function of the load and of the study objective. If the loading and operating conditions are constant, a short period (30-60 minutes) of data capture is sufficient. If a comprehensive statistical sampling of harmonics is needed, data must be captured for a longer period of time (24 hours or more).

HARMONIC ANALYSIS STUDIES

The V-HARM program by Cooper Power Systems is used to perform steady state harmonic analysis studies. Models can be of single or three phase systems. Harmonic loads are typically modeled as harmonic current injections (sources). On-site field data, if available, can be used to model harmonic producing loads and to test the accuracy of digital computer models. If actual data is unavailable,

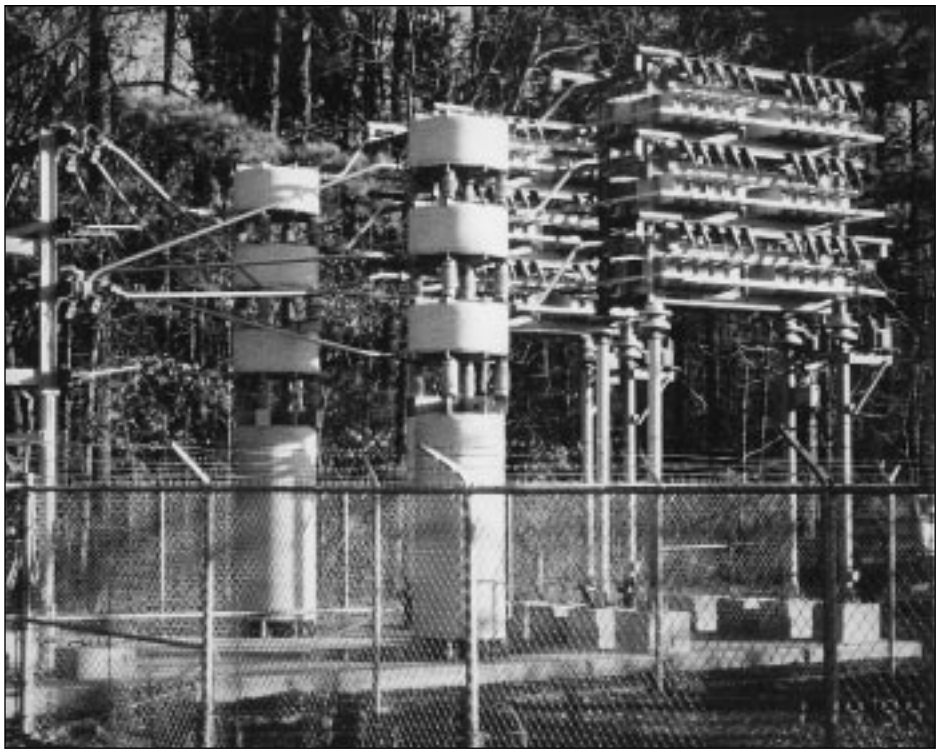

Figure 6.
Harmonic filters in operation at an industrial plant.

typical data based on experience with similar equipment is used.

These studies yield results like harmonic current flows and resulting voltage distortion levels. Large systems can be modeled since there are no restrictions on the number of buses that can be evaluated. Studies determine harmonic resonant frequencies using resonance scan plots, and calculate harmonic voltage and current levels throughout the system. Harmonic mitigation techniques, like harmonic filter designs, can be modeled and analyzed prior to actual installation. IEEE Standard 519 limits can be compared to operating conditions and alternate system designs can be easily evaluated to meet the guidelines.

HARMONIC FILTER DESIGN STUDIES

Harmonic filters are designed to suppress system harmonics as well as to improve power factor. They allow a system to meet IEEE Standard 519 harmonic limits while avoiding power factor penalties. Filter designs are tailored to individual project objectives such as meeting a harmonic limit and/or a power factor level. This is a complex and involved engineering task, where alternative designs are checked to ensure that the final one will meet study objectives.

Typically, single tuned shunt filters are designed with a reactor and capacitor in series, connected as a shunt load on the system. In more complex studies, other types of filters, like 2nd or 3rd order, C-type, and/or double tuned filters are designed. In a complex filter design, a combination of filter types could be required.

Once the filter type and the components (reactors, capacitors and resistors) are determined, the V-HARM program is used to model these filters. Overall power system operation can then be analyzed to determine the effectiveness of the filtering scheme. Ratings of all filter components along with the protection schemes and control methods are identified, and detailed specifications are developed for the manufacture of the filters. All designs are based on relevant IEEE Standards for capacitors and reactors. Other international standards are used if specifically requested by the customer.

Once a design is finalized, Systems Engineering will work closely with the Cooper capacitor plant, or other manufacturers in the actual production of the filter bank.

OTHER ANALYSIS PRODUCTS AND SERVICES

Harmonic measurements, analysis and filter studies are part of a comprehensive package offered by Systems Engineering. Related products and services include:

- On-site measurement services for transients and voltage flicker.
- Comprehensive transient analysis studies using digital computer models and the Transient Network Analyzer (TNA).
- Comprehensive voltage flicker analysis studies using digital computer models.
- Power Verdict™ Series software developed by Systems Engineering to analyze and troubleshoot power systems.
- System studies for power factor correction, power flows, short circuits, protective device coordination, motor starting and stability.
- Technical workshops covering electric power distribution issues including Power Quality and Harmonic Analysis.
- On-site training on application of harmonic filters.
- Technical publications written by Systems Engineering related to harmonics.

For more information contact your Cooper Power Systems representative or:

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