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Harmonic Filter & Power Capacitor Bank Application Studies

Summary

This document describes NEPSI's standard Harmonic Filter and Capacitor Bank Engineering Evaluation. It outlines the typical analysis performed by NEPSI in evaluating the possible negative system impacts related to the installation and switching of medium voltage harmonic filter banks and shunt capacitor banks and the application of non-linear loads such as arc furnaces, variable speed drives, induction furnaces, rectifier systems, and cycloconverters.

The engineering evaluation described in this document is centered on the design, specification, and system impact of new and/or existing capacitor banks and harmonic filter banks and the installation of large non-linear loads.

The studies described in this document are general in nature, and illustrate the engineering capabilities of NEPSI. All evaluations vary to some degree, and are dependent upon system characteristics and the type of equipment.

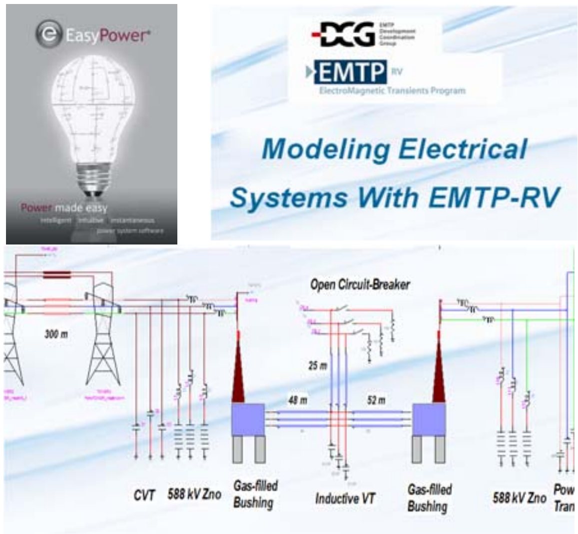

Figure-1: *NEPSI Power System Engineers Utilize Industry Standard and Accepted Software Packages to Perform all Power System Analysis.*

Introduction

The installation of a large shunt capacitor bank or harmonic filter bank or the addition of non-linear loads raises concerns primarily in the areas of harmonic distortion, harmonic resonance, switching surges, and possible over voltage conditions. It is prudent to perform a capacitor/harmonic filter bank evaluation before equipment is purchased so that any adverse conditions or added costs can be accounted for and identified in the design stage.

These concerns are typically evaluated by on-site power system measurements and digital simulations using sophisticated power system software. The measurements provide the ambient distortion levels, operating voltage, and other data required to validate and perform digital simulations. The digital simulations calculate system performance, and are used to predict and mitigate power system problems before they occur, so that special design requirements and cost can be accounted for in the planning stages.

Typical Scope of Work *Capacitor/Harmonic Filter Bank/Large Non-Linear Loads*	
Power system measurements and data collection	Filter/capacitor bank design and specification
Harmonic analysis	Transient Analysis
Short circuit analysis	Load flow analysis

Technical Approach

Task 1—Power System Measurement & Data Collection

The primary purpose of this task is to collect the necessary data to perform the power system evaluation and analysis for normal and abnormal system conditions as well as future system conditions or enhancements. It involves power system measurements, data validation, and discussions with plant personnel.

Data Collection and Validation

Data required to perform the power system analysis is typically collected by a NEPSI engineer while power system measurements are being taken. The data collected will typically consist of some or all of the following:

Typical Data Requirements *Data Required for Power System Evaluation*	
Short Circuit Impedance data, including one-line diagrams	Voltage Rating and locations of all capacitor banks and harmonic filter banks
Utility System Data	Normal and abnormal system conditions and operating practices
Digital Copy of system data if available	Equipment ratings and relay settings when necessary to perform study
Future Expansion and/or system changes	List of large non-linear devices

Power System Measurements

Power system measurements are taken to quantify the existing power factor, load level, operating voltage, harmonic distortion levels and other power quality concerns.

In some cases capacitor banks and or loads may have to be switched off to collect pertinent data, such as background distortion levels. If this switching operation is necessary, a plan to do so will be submitted in advance for consideration and approval.

Figure-2: *NEPSI utilizes several instruments for power quality monitoring including the Reliable Power Meter (RPM) by Fluke, the Fluke 43 for spot measurements, and the Hioki 3196 Power Quality Analyzer. NEPSI also uses the Lightwires Primary Power Analyzer (by SensorLink) when PT and CT signals are not available. This system allows for direct Medium Voltage Measurement of medium voltage overhead lines and bus bars using the Fluke 43.*

Task 2—Harmonic Analysis

Harmonic analysis involves the use of sophisticated computer programs to identify and predict potential harmonic problems and mitigation techniques. NEPSI's harmonic analysis program provides help in the identification of harmonic problems. Significant program output features include:

- Harmonic Impedance Scans
- Harmonic Amplification Scans
- Voltage and current distortion calculations
- Sensitivity analysis

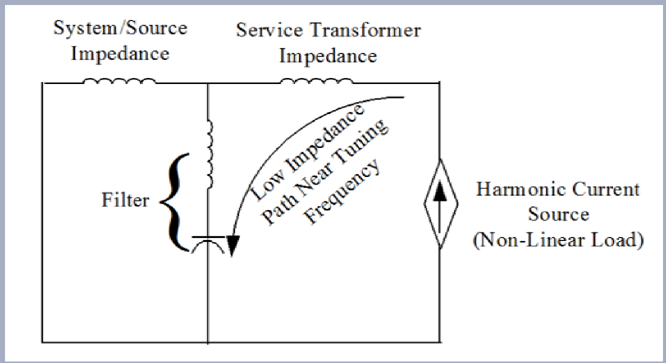

Figure 3: *Equivalent Circuit for Harmonic Analysis of a Simple System*

Harmonic Impedance Scans

Impedance scans are typically used to determine where resonant conditions exist. They are basically an impedance versus frequency plot of the system looking from the harmonic current source. Figure 4 shows such an impedance scan for various system configurations.

Typically, impedance scans are developed for normal and abnormal operating conditions as well as future expansions.

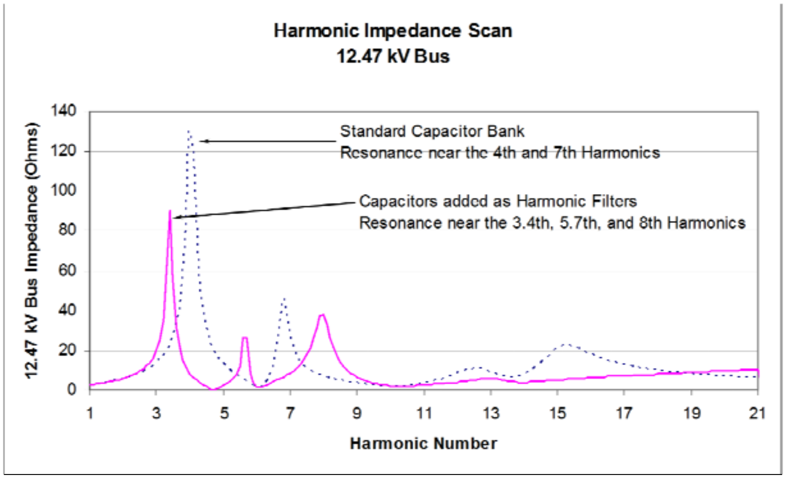

Figure 4: *Typical Impedance scan Showing Effect of Filter Bank and Capacitor Bank on System Impedance*

Current Amplification Scans

Current amplification plots have the same general appearance as impedance scans, but they have a totally different meaning. These plots show the current magnification/attenuation versus frequency at a given bus for a one amp injection at another bus in the system. These scans are typically used for finding localized resonant problems and would greatly aid in the identification of negative interaction between the plant's non-linear loads and the capacitor/filter bank. In addition to the scans above, voltage distortion calculations will be performed throughout the power system to confirm that the system meets IEEE 519 requirements for voltage and current distortion. Other standards or limits may be used at the request of the customer.

IEEE 519 Compliance Reports and Distortion Calculations

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Sensitivity Analysis

Sensitivity analysis is very important when doing harmonic analysis. Variations in capacitor and reactor impedances, as well as source impedance can greatly affect the voltage and current distortion calculations. This feature of NEPSI software will be utilized in this study to determine if any adverse system conditions exist due to slight variations in system and/or equipment impedances. The feature is especially useful in the design of harmonic filters where the worse case harmonic duties must be calculated.

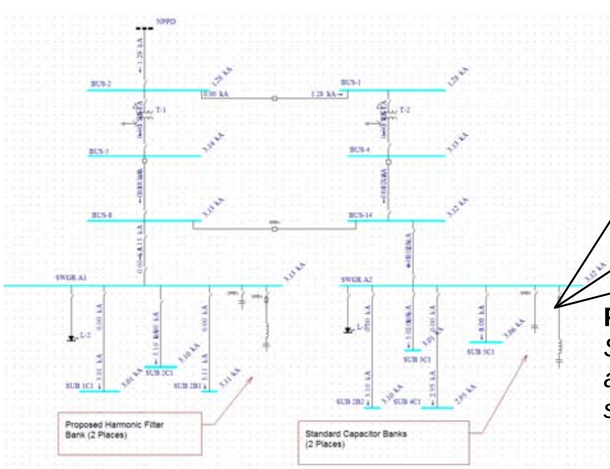
Data Requirements for Task 2—Harmonic Analysis

It is expected that the customer will provide the type, ratings, and location of harmonic generating loads and capacitors/filters within their power system as part of task one. Future harmonic load growth, as well as future system changes should also be provided.

Task 3—Short Circuit Analysis

A short circuit analysis is used to calculate system fault current levels to determine the interrupting and withstand adequacy of the power system equipment and associated protective devices. It also provides a guide in the selection and rating or setting of protective devices such as direct-acting trips, fuses, and relays.

The short circuit analysis described in this evaluation is typically limited to the major buses (nodes) and equipment connected directly to the capacitor/filter bank or large non-linear load. It may be expanded to include other busses at the customer's request, in which case a specific work scope would be developed. The short circuit calculation accounts for local generation, utility impedance, and short circuit current contributions from motors. The cases selected for the short circuit calculation will depict the power system configuration for which the three phase bolted fault short circuit currents will be at a maximum. All comparisons of interrupting device short circuit ratings or capabilities are to be based on this "worst case" condition.



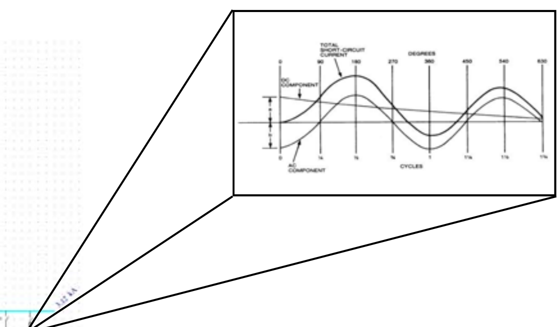


Figure 5: *The ESA Power System Analysis Software utilized By NEPSI employs algorithms in accordance with ANSI standards for determining short circuit duty ratings*

The short circuit study compares calculated short circuit duties with the first cycle and interrupting ratings of the medium and high voltage circuit breakers and fuses in the system. Low voltage device interrupting ratings (when involved) or capabilities will be compared against the first cycle fault magnitudes for each low voltage load center substation as defined in the scope of work. The load buses and equipment examined are those defined in the scope of work. Short circuit currents are calculated using R and JX impedance's by a digital computer in accordance with the American National Standards Institute (ANSI).

Typical deliverables from a short circuit analysis include:

- Recommendations
- Discussion of results and cases
- Table of breaker ratings and faults duties
- One-line diagram showing fault contributions
- Computer output with explanation of system configurations

Also included in the report will be a bus-to-bus listing of impedances used in the short circuit calculations. This listing is a part of the short circuit computer printout for each case calculated. The impedance listing and computer printout are referenced to the one-line diagram through the designated computer bus numbers and names.

Data Requirements for Task 3—Short Circuit Analysis
Typical data required for a short circuit analysis is as follows:

- One-line diagrams showing cable, transformers, breakers, reactors and motor equipment.
- Voltage and current rating and MVA sizes of equipment.
- Transformer impedances.
- Cable sizes and lengths.

Task 4—Load Flow Analysis

A load flow analysis is conducted to predict power flow magnitudes, power factor, voltage levels and losses in branches of the system based on the specified operating conditions. The results of the study are typically used to determine one or more of the following:

- Recommended transformer tap settings to maintain proper voltage level.
- Size of capacitor/filter banks to maintain an acceptable power factor and voltage level.
- Equipment rating (Ampacity).
- Contingency Analysis
- Losses

Typically, the load flow study will investigate system steady state load performance under normal and abnormal operating conditions. All significant system loads (watt and var components) and power sources (utility, co-gen, etc.) relating to the filter/capacitor bank installation are modeled. Where possible, system equivalents may be developed. The modeling can be expanded to include more of the system at the request of the customer, in which case, a specific work scope will be developed.

Data Requirements for Task 4—Load Flow Analysis
Typical data required for the load flow analysis is as follows:

- Load (MW and power factor) and process schedule.
- Voltage criteria on high and low voltage buses.
- Plant power factor requirements.
- Transformer tap ratings and settings.
- Normal and abnormal system conditions
- Impedance data.

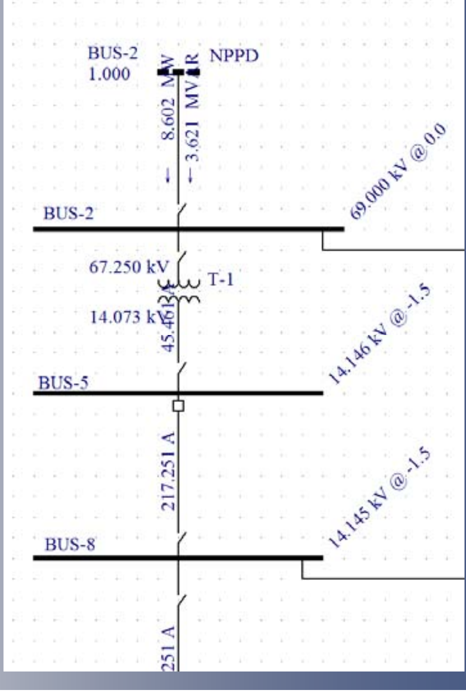


Figure 6: *The ESA Power System Analysis Software provides results of load flow analysis directly onto a one-line diagram for easy analysis of load flow results*

Task 5—Switching Surge Analysis

Switching surges occur during most switching operations. They occur during the transition when the system is changing from one steady state operating condition to another (this occurs during energization and de-energization of all equipment). The magnitude of the switching transient depends upon switching time and the resistive, capacitive, and inductive characteristics of the system. Capacitor switching and miss-operation of switches due to re-strike and pre-strike generally cause the more severe switching transients.

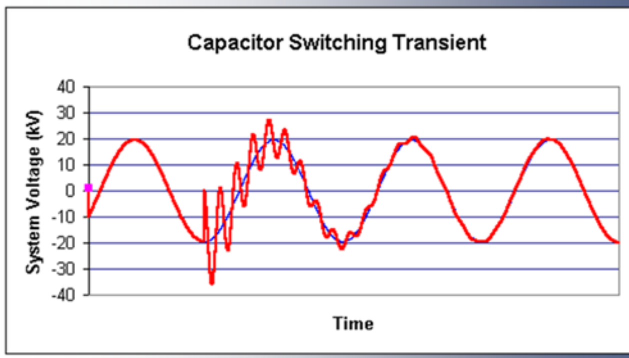


Figure 7: *Typical Waveform Plot Produced By EMTP*

The Electromagnetic Transients Program (EMTP) is typically used to investigate switching transients and can produce actual waveforms as shown in Figure 7. Transient simulation models may require more detail than 50/60 Hz models used in load flow, short circuit, and harmonic analysis programs. Due to this increased level of detail, the circuit elements of concern are usually modeled in detail, while the remainder of the system is modeled as a lumped circuit parameter.

For the application of capacitor banks and harmonic filter banks, switching surge analysis is usually conducted for one or more of the following reasons:

- Rating of transient inrush reactors for back-to-back switching operations
- TRV calculations on feeder circuit breakers
- Confirmation of switch ratings for inrush current and frequency
- Pre-insertion resistor rating and optimization
- Pre-strike and Re-strike evaluation

Data Requirements

Data required to do switching surge analysis is usually quite detailed. This data request will consist of data required to do short circuit and harmonic analysis but will require detailed data on components of concern.

Task 6 - Filter Bank/Capacitor Bank Design Specification

This task involves the design and specification of the capacitor/filter bank. It draws on the results from previous tasks. The Capacitor/Filter bank performance is usually evaluated as part of the load flow and harmonic analysis task. Short circuit requirements are evaluated in the short circuit analysis task. This task involves the functional specification of the specific components within the filter/capacitor bank to meet the performance requirements found necessary in the previous task. A guide form specification is provided so the customer can go out for competitive bid.

The specification will typically contain the following:

- Capacitor ratings
- Reactor ratings
- Filter bank configuration
- Protection requirements
- Switch requirements
- Disconnecting requirements
- Layout requirements
- Warranty requirements
- Transient inrush reactor requirements
- Control requirements

Figure 8 shows typical industrial and utility power system filters that are typically designed by Northeast Power Systems, Inc. The C-Type filter offers the advantage of low fundamental losses that are commonly found in other high pass filter designs.

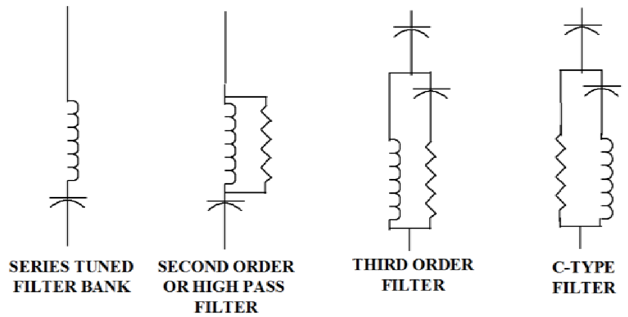


Figure 8:*Typical Harmonic Filter Designs*

Figure 9:*Typical Harmonic Filter Bank Specified by Northeast Power Systems, Inc.*