A SIMULATION-BASED SPECTRAL STRATEGY FOR
POWER FILTER DESIGN IN AN ELECTRICAL SYSTEM

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Abstract

A simulation-based spectral strategy for power filter design has been developed, which allows a designer to identify and solve the EMC and the power quality problems in the earlier phase of electrical system design. The proposed spectral strategy is independent of the circuit of the designed filters, and provides full solution of the electric power quality problem in the electrical system. The strategy has been applied to designing a power filter for an electronic device with a linear power supply.

1 Introduction

In electrical systems with a power source generating a power comparable to the consumed power, e.g. in motor vehicles, aircrafts, ships, etc., solving the EMC problems is directly related to the power quality issues. The higher the conducted emissions in the electrical system the worse the quality of the electric power delivered from the power source and the less efficiently it is utilized. In many practical cases an electrical system includes a three-phase synchronous generator acting as a power source, a power distribution network, three-phase power converters and electronic devices or products connected to the power distribution network via power cords. Electronic devices include power supplies. Three-phase power converters and power supplies, as a rule, include three-phase filters and EMC filters, respectively.

In the earlier phase of electrical system design both the EMC and the power quality problems have to be identified and solved both for the situation where the elements of the electrical system are known and the system response is specified, and for the situation where the electrical system response is changed due to malfunction of a three-phase filter or an EMC filter. The problem identification is performed according to the governmental regulations in the field of EMC and power quality. As a solution for the EMC and the power quality problems an additional power filter has to be designed.

In the context of solving both the EMC and the power quality problems, a power filter is an electric circuit separating and reducing reactive powers characterized by the total harmonics distortion, the displacement power factor, and the voltage unbalance. The latter has to be considered when designing three-phase filters only.

The simulation-based spectral strategy for power filter design allows a designer to identify and solve the EMC and the power quality problems in the earlier phase of the electrical system design. This strategy is based on the multiple calculations of current and voltage spectra in the nodes of the electrical system during the filter design.

The spectral strategy essentially differs from the filter design methods based on the insertion loss technique [3], since it searches for the electrical system frequency response and for the corresponding filter circuit given the requirements for the power quality in the electrical system. Alternatively, the insertion loss technique requires in-advance specification of the frequency response of an electrical system and does not explicitly consider all the power quality requirements.

In the spectral strategy three-phase power converters are described by complete non-linear model. On the other hand, in the techniques based on transfer functions the model of the electrical system is expected to be linear [3], which also makes it difficult solving the power quality problem.

2 Problem statement

The problem of power filter design is stated for the electrical system shown in Figure 1. The electrical system includes a three-phase synchronous generator SG, a power distribution network, a single-phase power line routing from node 3 to node 4, and electronic devices or products connected to the single-phase power line at node 4 via power cords PC

\[ i = 1, 2, \ldots, n \] . A power supply (a switched-mode power supply or a linear power supply) of the i-th product is the primary source of high-order current harmonics in the power cord PC

\[ i = 1, 2, \ldots, n \] . The three-phase filter F

\[ i = 1, 2, \ldots, n \] reduces the emission...
of high-order current harmonics from the controlled rectifier bridge B. Malfunction of the filter $F_h$ can result in the reduction of immunity of the electronic device to conducted emissions due to poor power quality in the power distribution network. The EMC filter $F_i$ is embedded in the product's enclosure as a part of the product's power supply $P_s$.

Typically, only the emission from the power supply is taken into account in the EMC filter design. The immunity of susceptible components in the power supply load to the external conducted emissions is typically not considered for the situations where the power quality is poor. In case of malfunction of the EMC filter $F_i$ emission of high-order current harmonics to the power distribution network increases. Therefore, an additional power filter $F_a$ is required in case when the filters $F_h$ and/or $F_i$ fail to solve the power quality and/or the EMC problem (see Figure 1). Designing the filter $F_a$ is implemented in the filter design strategy introduced below.

![Figure 1: Schematic of an electrical system.](image)

### 3 Spectral strategy for power filter design

A block diagram of the simulation-based spectral strategy for power filter design is shown in Figure 2. The strategy includes the following steps.

**Step 1. Specifying electrical system structure and parameters.**

In this step, elements of the electrical system are defined by their component values such as resistance, reactance, capacitance and inductance, the electrical characteristics such as total power of a three-phase synchronous generator, and the control parameters, such as commutation delay angle. The power quality in the electrical system is presented by the total harmonics distortion, and the displacement power factor, which are referred to as the electric power quality indices. They are brought to the electric power quality matrix (EPQ-matrix) [1]. The desired EPQ-matrix has to be specified. Each row in the EPQ-matrix corresponds to a node in the electrical system, and each column corresponds to an electric power quality index.

**Step 2. Forming an updated EPQ-matrix.**

Current and voltage spectra both in the power cords of products and in the products' sensitive components are calculated. This procedure utilizes a complete differential model of the electrical system to reflect essential non-linear processes in the elements of the electrical system. This is primary the case when controlled rectifier bridges and switched-mode power supplies are modelled. In this step a set of ordinary differential equations with discontinuous right-hand members is numerically solved in the time domain, and preliminary static stability analysis is performed applying the QR-technique [4]. The calculated voltage and current spectra are then used for forming an updated EPQ-matrix.

**Step 3. Comparing the desired EPQ-matrix with the updated EPQ-matrix.**

The desired EPQ-matrix is subtracted from the updated EPQ-matrix. If the updated EPQ-matrix and the desired EPQ-matrix coincide or if the matrix difference contains the elements with the absolute values smaller than the tolerance values specified for each power quality index, then the task of designing the power filter is already solved. Otherwise, an expert decision has to be made.
Maximum Load Capacity and Main Circuit Design of Voltage Sag Compensator Using Double-Layer Capacitor

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Abstract

A novel voltage sag compensator with double-layer capacitor is presented. The discharge characteristics of the double-layer capacitors and the maximum load capacity of the system are investigated on the basis of the equivalent circuit including capacitors and a voltage booster. Furthermore, main circuit design of the system is explained. Finally, simulation results show the validity of the design and the ability of the compensator.

1 Introduction

Power service interruptions cause problems in various facilities. Even voltage sag may give rise to serious problems in computer systems or electronic equipments. The uninterruptible power system (UPS) has been used to compensate for the power service interruptions. The system, however, needs maintenance for the lead acid battery and the battery lifetime is not so long.

Recently, the double-layer capacitor is paid attention as a new energy storage element. This capacitor has a lot of advantages such as no maintenance, long lifetime and quick charge/discharge characteristics with large current. Some papers for applications of the double-layer capacitor have been published. In reference [1], the double-layer capacitor is used for power smoothing and absorbing regenerative energy in elevator applications. In reference [2], the capacitors are attached to the dc link of adjustable-speed drive system through the flyback converter to compensate the dc link voltage drop during short-term power interruptions.

We use the double-layer capacitor as a storage element of the UPS system. In this paper, a novel voltage sag compensator with double-layer capacitor is presented. The discharge characteristics of the double-layer capacitors and the maximum load capacity of the system are investigated on the basis of the equivalent circuit including capacitors and a voltage booster. Furthermore, main circuit design of the system is explained. Finally, simulation results show the validity of the design and the ability of the compensator.

2 System configuration

The system configuration of proposed voltage sag compensator is shown in Fig.1. The lead acid battery in the conventional UPS was exchanged to a set of double-layer capacitor and bi-directional voltage booster for our new voltage sag compensator. Main circuit of the system mainly consists of the PWM converter, the energy storage element (i.e. double-layer capacitor) and the PWM inverter. The voltage booster is used to control the charging current to the double-layer capacitor and also used to keep the dc link voltage constant for the discharge of the double-layer capacitor. The control circuit consists of the power failure detector, the PWM converter controller, the PWM inverter controller, the voltage booster controller and the control circuit for switching between series and parallel connections of the double-layer capacitor banks.

In normal situation, the electric power to the load is provided from power grid through the PWM converter and the PWM inverter. Then the input current is controlled to keep unity power factor by the converter. In this situation, the double-layer capacitors are charged with constant current. After the voltage became full, the voltage across the double-layer capacitor is kept constant by the voltage booster. And the dc link voltage is also kept constant by the PWM converter.

When power failure occurs, the source of the electric power is transferred from the power grid to the double-layer capacitors. The power from double-layer capacitor is provided to the load through the voltage booster and the PWM inverter. In failure situation, the dc link voltage is kept constant by the voltage booster. This system can compensate for not only the voltage sag but also the short-term power interruption.

We choose 55V as the input voltage (line voltage), 100V as the dc link voltage and 55V as the output voltage (line voltage) for our simulation in this paper. And the values of parameters of a double-layer capacitor are 2.5V, 5175F and 2.2mΩ.

We assumed two capacitor banks to investigate the optimum usage of the capacitor. Each bank consists of 50-series-connected capacitors. The connection of the two banks is switched between series and parallel depending on the capacitor voltage. Since no active voltage-sharing devices are used, we assume that each capacitor bank is