Power Conditioning Equipment for Improvement of Power Quality in Distribution Systems

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Abstract - As awareness of power quality issues increases, utility customers are demanding higher quality, more reliable supply. On the other hand, utilities are responding to an increasing level of harmonics and flicker in the system with better monitoring and tighter regulation of distorting loads. This paper describes briefly the main power quality problems in distribution systems and ways of solving them using state of the art power electronics-based equipment, the so called Power Conditioner.

Keywords - Power quality, Harmonic distortion, Voltage sag, PWM converter

1. INTRODUCTION

Global deregulation of power markets, increased customer awareness and the increasing sensitivity of modern load equipment has resulted in utilities and customers alike taking issues of power quality more seriously than ever before.

The growing number of low pulse-number power electronic loads in distribution networks causes an increasing line voltage distortion. This phenomena has been observed around the world, as harmonic distortion on the distribution system has been rising, and in some cases approaching or exceeding compatibility limits [1].

Due to the sensitivity of modern high-tech industrial equipment, voltage sags and momentary outages are emerging as a significant concern of industrial customers. Insufficient supply quality can lead to degraded quality of products and interruption of critical processes, resulting in substantial economic losses. Commercial and residential customers also expect high supply quality, as the amount of equipment sensitive to inadequate voltage quality and outages increases.

This paper presents the basic configurations of a family of equipment called SIPCON (**Si**emens **P**ower **Con**ditioner) for improvement of power quality in distribution and industrial power systems. They are called „Power Conditioners“ in order to emphasize their versatile characteristics compared to active filters [2]. Active filters are usually referred to as equipment with the properties of time-variant passive filters.

The two basic types of system connection and topology are depicted in Figs. 1 and 2, and are similar to FACTS controllers (Flexible AC Transmission Systems), which have been developed for power flow control and stability improvement in high voltage transmission systems [3]. The basic ideas of FACTS can be applied to low and medium voltage distribution systems [4] with a focus on the particular problems of supply quality at fundamental and harmonic frequencies.

SIPCON is based on standard mass-produced motor drive converter technology, leading to a highly reliable and economical solution.

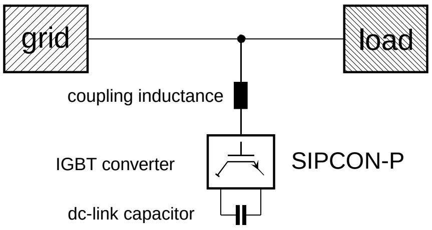


Fig. 1. Shunt connected Power Conditioner (SIPCON P)

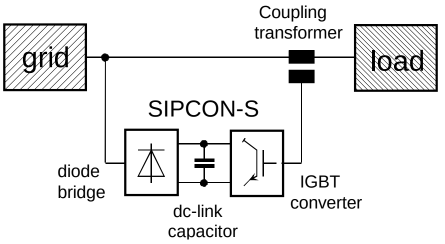


Fig. 2. Series connected Power Conditioner (SIPCON S)

2. POWER QUALITY ISSUES

The problems in power supply quality may be broadly classified into two categories:

- Non-ideal network supply voltages which affects load performance
- Distorting loads, which draw non-active current components (fundamental, harmonic and interharmonic frequencies) or fluctuating (flicker producing) currents, leading to voltage distortion across the network.

Supply Voltage Quality

An ideal network supply voltage is a continuous, purely sinusoidal waveform with constant nominal amplitude at network fundamental frequency. Any deviation exceeding the recommendations (e. g. [1,5]) may result in tripping or damage of load equipment. The predominant conditions of non-ideal supply voltage in distribution systems are voltage sags and swells, harmonic distortion and flicker.

Load Current Distortion

A load current which is not proportional to the line voltage contains non-active portions and the apparent power is greater than the transmitted active power. Typical non-active portions are harmonics, fundamental reactive and negative sequence portions. Fluctuating active- or non-active portions of the load current may produce voltage flicker across the network.

3. POWER CONDITIONING EQUIPMENT FOR DISTRIBUTION SYSTEMS

SIPCON was developed for improvement of power quality in low- and medium-voltage distribution networks. It fits within the general framework of EQM (**E**nergy **Q**uality **M**anagement). The cost-effectiveness of this equipment is a result of significant progress in recent years, with regard to the rating and price of power semiconductor technology.

Power Converter Equipment

The principal component of SIPCON is a pulse-width modulated (PWM) IGBT-converter (**I**nsulated **G**ate **B**ipolar **T**ransistor) being available with power ratings up to 925 kVA [6]. Fig. 3 depicts the basic IGBT converter topology, and the coupling filter used.

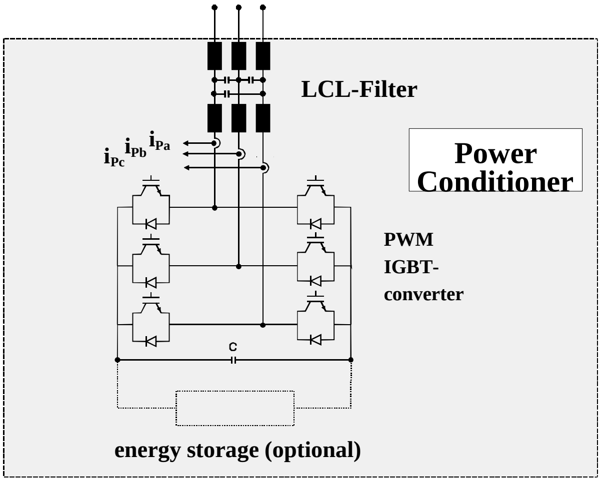


Fig. 3. IGBT converter and coupling filter circuit for power conditioning equipment

Control Hardware and Software

Control is effected in both time- and frequency domains as appropriate. The phase voltages and currents are transformed to a space vector coordinate system by an analog measurement card. The space vector representation provides information on both positive and negative sequence network quantities. The same hardware and software is used for both series and shunt applications. Generation of the control source code for the various Power Conditioner types is achieved through a software switch at compilation.

4. SHUNT CONNECTED POWER CONDITIONER

In general, the shunt-connected Power Conditioner (SIPCON P) is intended for optimization of the current flowing from a load into the network. It improves the network current. The connection of this device is three phase, in parallel with the network and the load as shown in Fig. 1. Connection to networks with voltage levels above 690 V requires a coupling transformer.

Control Tasks

The shunt connected Power Conditioner injects current into the PCC. The injected current compensates undesirable components of the load current. Currently 5 control tasks have been implemented for the shunt connected Power Conditioner, with two possible modes of operation:

- Standard active filter mode
- Flicker reduction mode

1. Standard active filter mode: The standard mode of operation features the following 4 control tasks:

- ***Active harmonic filtering***
- ***Reactive power compensation***
- ***Dynamic load balancing***
- ***Active power transfer***

These four control tasks may be performed concurrently.

2. Flicker Mode: A supplementary flicker algorithm has been developed for the shunt connected Power Conditioner, with a response time on the order of milliseconds.

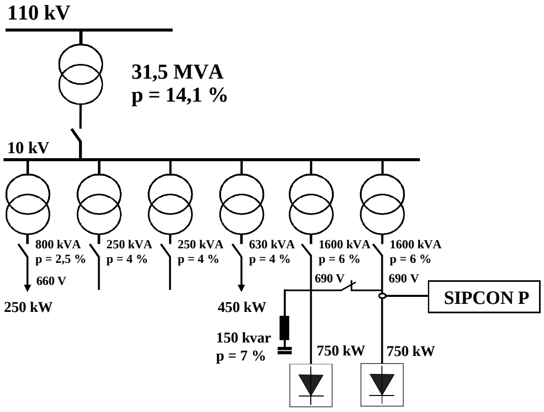
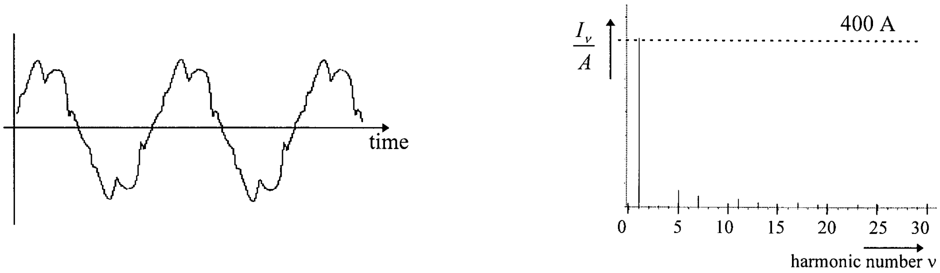


Fig. 5. Single line diagram of shunt-connected Power Conditioner installation (SIPCON P)

Application - Shunt Active Filtering

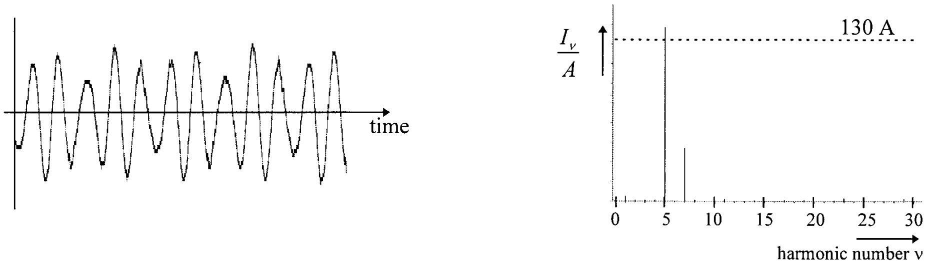
A shunt-connected Power Conditioner has been installed at an industrial site in northern Germany. This is the largest Power Conditioner in Europe to date, and has been operating successfully since December, 1996. Fig. 5 shows a single line diagram of the system and Fig. 4 time- and frequency-domain measurement results. The task of the Power Conditioner (power rating 610 kVA) is to limit the 5th and 7th harmonic currents originating from the diode rectifiers to preset values.

The motivation for installation of a Power Conditioner instead of conventional LC filters was



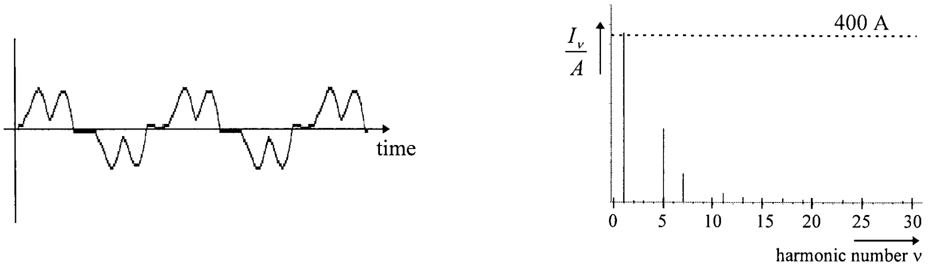
a) Network current

b) Network current spectrum



c) SIPCON current

d) SIPCON current spectrum



e) Load current

f) Load current spectrum

Fig. 4. Site measurements of active filter installation

the unwanted reactive power injection of passive filters and possible interference with ripple control signals transmitted across the power system.

5. SERIES CONNECTED POWER CONDITIONER

The series-connected Power Conditioner (SIPCON S) is coupled directly into the power flow via a transformer as shown in Fig. 2. The purpose of this equipment is the compensation of voltage distortion originating elsewhere in the supply network, and the protection of sensitive loads against voltage sags and swells.

Control Tasks

The two principal control tasks of the series connected Power Conditioner are

- dynamic compensation of voltage sags and swells.
- reduction of network voltage distortion at the load side

These 2 control tasks may be performed concurrently.

1. Voltage sags and swells. The vast majority of voltage sags reduce the supply voltage at the customer bus, on one or more phases, by no more than 30 %, and in general are unbalanced. These voltage sags, typically lasting between 100 and 500 ms, are much more common than complete outages [7]. A voltage component is injected in series with the supply network voltage, thereby compensating voltage sags and swells on the load side. Control response is on the order of milliseconds, ensuring a secure voltage supply under transient network conditions.

Voltage injection of arbitrary phase with respect to the load current implies active power transfer capability. This active power is transferred via the dc-link, and is supplied either by a diode bridge connected to the ac network, or by an energy storage device.

If diodes are used to supply the series connected Power Conditioner, active power may be supplied to the load by the IGBT - converter, but however can not be absorbed. Replacing the diode bridge by a 4 quadrant converter (e.g. thyristor or IGBT-based) leads to a Power Conditioner which can optimize load voltage under all system and load conditions.

2. Harmonic reduction. The series connected Power Conditioner can generate harmonic voltages. This capability can be utilized to compensate pre-distortion in the network voltages by injecting the opposite harmonic voltages.

Application -Voltage Sag Compensation

To verify the capability of the series connected Power Conditioner in mitigating realistic voltage sags, simulation studies have been performed using measured voltage sag waveforms from [8]. These waveforms were injected at the PCC by pre-programming a controlled voltage source. The focus of these simulation studies was compensation performed at medium voltage level for loads rated at several MVA.

Figure 7 shows the test system modeled for this study. In this case, the Power Conditioner is installed at the secondary side of the 69/13.8 kV transformer to protect an industrial load rated at 6 MVA. The load consists of a 4 MVA impedance load (power factor of 0.9) and two large induction

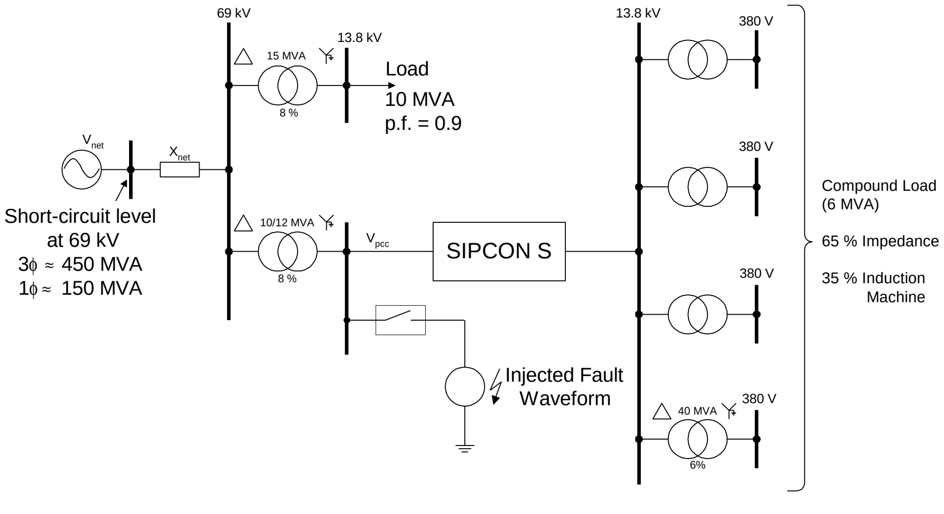


Fig. 7. Test system for study of series-connected Power Conditioner (SIPCON S) study

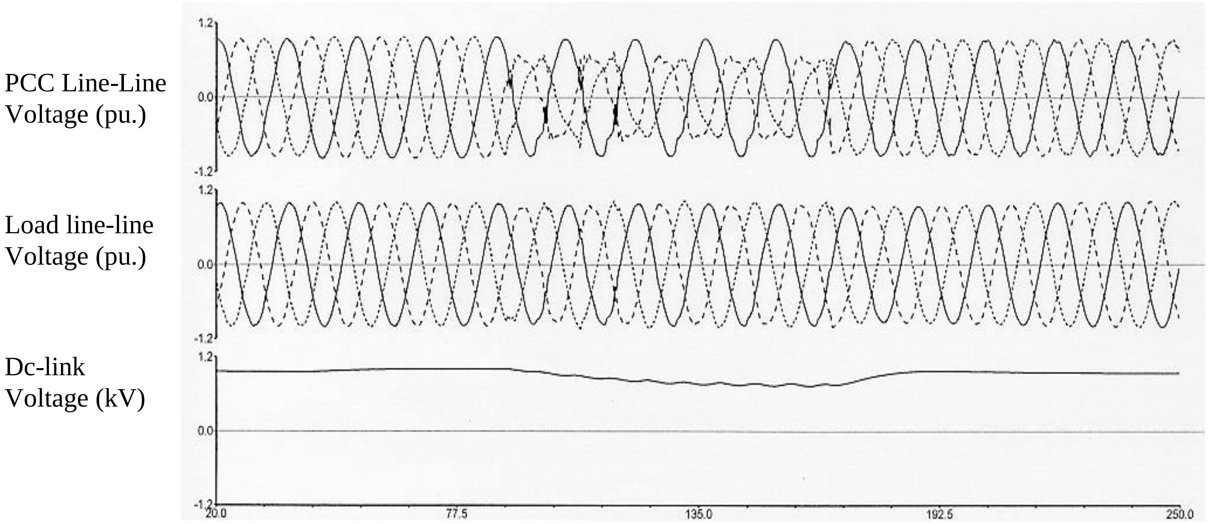


Fig. 8. Voltage sags on 2 phases by approximately 35 %.

motors, each rated at 1 MVA. The short circuit level seen at the 69 kV side of the load transformer is 450 MVA, with transformer winding arrangements and impedance as shown.

Figure 8 presents simulation results showing the effectiveness of the Power Conditioner in reducing voltage sags. In these plots, the line-line voltages at the PCC and load sides of the Power Conditioner are shown. Furthermore, the dc-link voltage seen by the IGBT converter is depicted.

In Figure 8, the PCC voltage sags on 2 phases by approximately 35 %. Furthermore, higher frequency distortion of the PCC voltage is also evident, presumably due to resonance excited by the fault. In this case, the Power Conditioner is capable of restoring the voltage seen by the load to 100 %. As was seen with the lab prototype, the response time is very fast (on the order of 1-2 ms.).

6. CONCLUSION

Due to the changing load characteristics of modern industry the requirements on the quality of electrical power supply are becoming more and more stringent. For an increasing number of cases these requirements can no longer be managed with purely conventional equipment. Power Conditioners offer the ability to solve simultaneously several power quality problems (e. g. reactive power, harmonics, unbalanced loading, voltage sags and swells, flicker), so that all consumers receive a sufficient quality of supply.

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