Power Quality Problems and its Solutions

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Abstract - This paper describes the power quality problems and its solutions in distribution systems. The quality of electrical power supply is a major problem of engineering task and the growing number of electronic-based devices have an impact on the power supply. In this case, passive filters are not applicable. Therefore, a new method for Power Quality using IGBTs and active power filter is presented which is suitable to compensate rapidly changing loads and reactive power. It also presents a brief discussion of the main problems in the distribution power systems.

Keywords: Power quality, compensator, reactive power, power factor, active filter.

I. INTRODUCTION

The increased use of non-linear devices cause voltage distortion in the network. This leads to malfunctions of the electric facilities and to costly interruptions of production. Reactive power appears in every power system and many loads consume not only active but also reactive power.

There is a strong coupling between reactive power balance and of a power system and the voltages. Today, many techniques are used to compensate the reactive power. Shunt and series compensation is widely used in the industry. Two possible loads can be discussed in this point of view. The non-linear supply voltage which influences the loads behaviour and non-linear loads which cause voltage distortions in other supply feedings.

The main characteristics of a non-linear supply are the voltage interruptions, harmonic pre-distortions and unbalance in the three phase systems. On the other side, the main characteristics of a non-linear loads are the harmonics, fundamental reactive current, unsymmetrical parts and the stochastic fluctuations called flicker.

In this paper a new method for power factor correction and harmonic current reduction is proposed. The filter circuit parameters are analysed and described. This filter configuration provides an alternative approach to the existing one. According to the test results, the hysteresis control seems to be a more suitable solution because it guarantees a stable operation for the whole system. The proposed approach can achieve a complete elimination of harmonics.

A power conditioner capable of compensating harmonics and reactive power was presented in [1]. In this paper harmonic currents of different orders as well as unbalance and reactive power of fundamental frequence were discussed using GTO thyristors. An active reactive power controller and lattice power circuit was also researched extensively [2]. A compensation strategy of capacitive loads by a voltage source inverter was investigated in [3]. A switching algorithm of a single-phase voltage source power convertion system was presented for the current waveform regulation [4].

In the past, extensive research related to the power factor correction and harmonic elimination was carried out. Filter circuits, dynamic compensation and conventional capacitors are in usage with some problems.

The development of power semiconductor technology such as GTO , IGBT and reduced price make it possible to solve power quality problems. It improves the quality of the supply voltage and the network current.

II. POWER QUALITY PROBLEMS

Active filtering: The current flowing from the load into the network is measured and divided into fundamental and harmonic components and the current is injected into the network.

Dynamic reactive power compensation: the reactive power is supplied stepless in both capacitive and inductive modes into the network.

Active load balancing: the positive and negative sequence current can be injected into the PCC and negative sequence current associated with unbalance load conditions is then eliminated.

Flicker compensation and voltage fluctuation: variation in the brightness of lighting systems in the 10 Hz region is called flicker which caused by sudden stochastic load current peaks which cause voltage drops at the PCC across the network impedance. Voltage fluctuation can result from switching or variations of loads.

Voltage sags and swells: voltage sags and swells are the most severe power quality problem. They often occur due to lightning and customer voltage drops below the nominal value on one or more phases. The interruption time depends on the network configuration and protection.

Harmonics: harmonic currents are injected into network power supply by the non-linear loads. As a result, harmonic voltages which appear across the power system impedances are superimposed on the fundamental frequency and thus distort the system voltage. This can lead to malfunctions and disturbances of the consumers. Traditionally, harmonics can be dealt with by the use of passive filter may result in parallel resonances with the network impedance.

Voltage unbalance: single-phase loads cause voltage unbalance in the network.

Transients: lightning and switching operations cause transients in the system. The duration of transients is typically a couple of nanoseconds up to few miliseconds.

This paper treats some of the above problems such as active harmonic filters and dynamic reactive power compensation.

Fig. 1. represents very important definitions of the power quality problems.

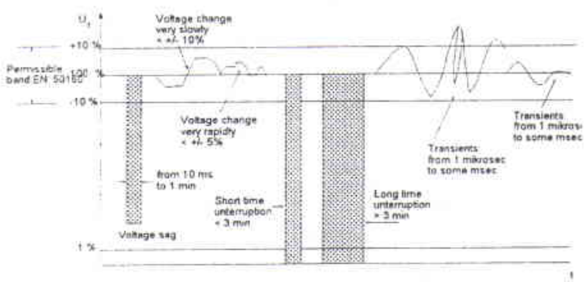

Fig. 1. Definitions of power quality

III. CONTROL SYSTEM

The improvement of power quality depends on the source of the problem which can occur either on the medium (supply) or low voltage (consumer) side. The inverter injects current into the system (PCC) which compensates for undesirable components of the load current. The current, flowing from the load into network, is measured. The filter circuit filters out harmonics (Fig.2). This circuit can also supply continuos reactive power.

Today, the switching devices are used in the electric power system more often to increase the productivity and power quality. On the other hand all these devices produce harmonics, voltage distortion and reduction of power factor. At present there exist many methods to eliminate or reduce the effects of the harmonics on the power systems.

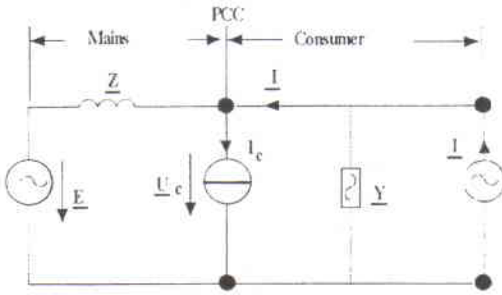

Fig.2. Single line diagram and equivalent circuit of a power system

Power factor improvement in power systems with non-sinusoidal supply voltage has been a subject of concern for a long time. As a consequence, various types of compensators have been developed to improve the efficiency of power transmission and distribution to increase the power factor.

A self-commutated voltage source inverter is used because:

- simple control algorithm is possible.
- it generates less current harmonics.
- it can be controlled continuously.
- it has an excellent dynamic system.
- the device can be used frequently because of the working reliability and lower price.

A typical power system with inverter and loads used for the study is shown in Fig.3.

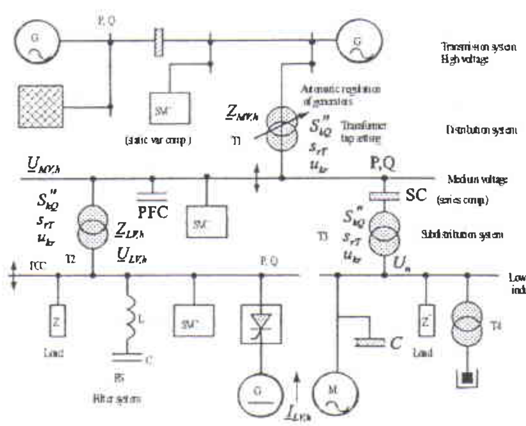

Fig. 3. System used for the study and analysis

Fig. 4 presents an equivalent circuit with filter and mains.

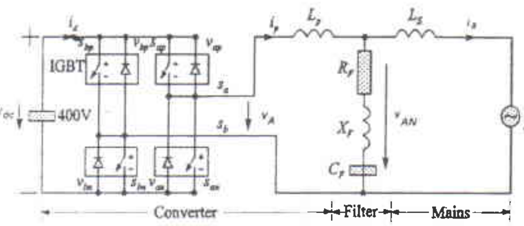

Fig. 4 Single-Phase Full Bridge Inverter-Filter Scheme

At a given node (PCC), the supply system consists of various voltage sources, current sources, network impedances and load impedances which are connected to other nodes. Knowing that the harmonic current $\underline{I}_h$ and network impedance $\underline{Z}_h$ is given, the voltage distortion can be calculated as

$$\underline{V}_h = \underline{Z}_h \, \underline{I}_h \qquad (1)$$

The network impedance $\underline{Z}_h$ is

$$\underline{Z}_h = \left(\frac{\underline{Z}_F \, \underline{Z}_s}{\underline{Z}_F + \underline{Z}_s} \right) \qquad (2)$$

Where $\underline{Z}_F$ is the filter impedance.

A voltage source inverter (VSI) is used to eliminate the harmonics and increase the power factor in the power system. At the output of the VSI an inductance L_p is connected to limit the inverter current. To reduce and to eliminate the harmonics in the fundamental current i_s and in the power network voltage v_A a filter is implemented which contains a filter resistance R_F, a capacitor C_F and an inductance L_F. The internal reactance of the main power system is given by the inductance L_S. The VSI consists of two IGBT switching devices in parallel with one diode. The two switches (TOP and BOTTOM) are operated in antiphase so that the current i_p flows through the two branches alternately.

Magnitude and phase change between inverter output desired current $i_{p,dv}$ and main network current i_s is given by:

$$i_{p,dv} = \hat{i}_{p,dv} \sin(\omega t - \varphi) \qquad (3)$$

The actual current value i_{act} is kept with a constant scanning period of time. If the current reaches one of the boundaries, then an inverter switching is required after the delay time T_D (Fig.5).

Normally, the main network acts as an ohmic-inductive consumer and the computation can be performed with a given supply power P_s and a power factor $\cos\varphi$. Then the peak value of the sinusoidal desired current $i_{p,dv}$ can be calculated as

$$\hat{i}_{p,dv} = \frac{\hat{i}_s}{m_{i-pn}} = \frac{2P_s}{\left[\hat{V}_S \left(\cos\varphi_{n,dv} \right) m_{i-pn} \right]} \qquad (4)$$

Where m_{i-pn} is the correction factor for the desired value it is given by:

$$m_{i-pn} = \sqrt{\frac{R_F^2 + \left(\frac{1}{\omega C_F} \right)^2}{R_F^2 + \left(\omega L_S - \frac{1}{\omega C_F} \right)^2}} \qquad (5)$$

The phase correction is defined as:

$$\varphi_{i-pn} = -\left[\arctan\left(-\frac{1}{\omega R_F C_F} \right) - \arctan\left(\frac{\omega L_S - \frac{1}{\omega C_F}}{R_F} \right) \right] \qquad (6)$$

The value of the inductors, the pattern of the switching functions and the filter characteristics define the network current. Basically the PWM pattern can be used for the control of the inverter to generate a desired output current waveform.

According to the test results the hysteresis control seems to be a more suitable solution because it guarantees a stable operation.

Fig.5 shows the tracking strategy for the hysteresis control. The control current is sampled with a tolerance bandwidth and evaluated in the control unit.

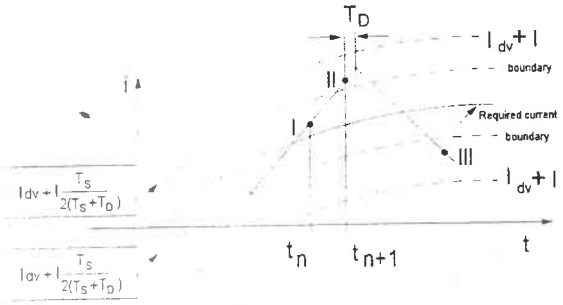

Fig. 5. Principles of the tracking strategy for the two-step-control

As described in [4] a sampling control is used and a load is applied to the inverter which requires only the control of the fundamental current for power factor correction. In this paper, it is shown that the circuit is capable of correcting not only the power factor of the fundamentals but also of eliminating the harmonics.

To achieve a hysteresis control band width I_δ the current, which is controlled, can be calculated from:

$$2\, I_{tol} = 2\, I_\delta \frac{T_S}{2\left(T_S + T_D\right)} . \tag{7}$$

The sampling method and switching modes of the inverters is given in Table 1. A direct switching from state I to the state III must be avoided. The switching state for the IGBTs are S_{ap}, S_{bn}, S_{bp} and S_{an}.

Table 1. Scanning method of the inverters

i_p	S_{ap}	S_{bn}	S_{bp}	S_{an}	$u_{A(t)} = U_{dc}$
I	1	1	0	0	+
II	1	0	1	0	0
III	0	0	1	1	-

IV. ANALYSIS OF THE FILTER CHARACTERISTICS

To avoid the harmonics in the main power current and supply voltage a filter is designed and applied to a single VSI as shown in Fig.4. The filter resistance R_F is inserted to restrain the oscillation of the capacitor of the network and inverter inductance. A lower value of R_F gives the best results of the smoothing of the network current and supply voltage.

On the other hand, the filter capacitor C_F must be large enough to absorb the current and voltage ripples. In order to limit the failure current the following equation gives:

$$\frac{I_\delta \left(L_S + L_p\right)}{2\, V_d} \geq \left(T_S + T_D\right) . \tag{8}$$

The resonance frequency of Fig. 4 is:

$$f_r \leq \frac{1}{2\pi} \sqrt{\frac{L_S + L_p}{L_S\, L_p\, C_F}} . \tag{9}$$

To avoid the resonance frequency, the following assumption can be made with sampling frequency f_S:

$$f_S \geq 20\, f_r . \tag{10}$$

The filter capacitor C_F should be:

$$C_F \geq 10 \frac{L_S + L_p}{L_S\, L_p} T^2{}_S . \tag{11}$$

Then, the filter resistance R_F can be expressed as:

$$R_F = 0.15 \sqrt{\frac{L_S L_p}{C_F\left(L_S + L_p\right)}} . \tag{12}$$

The desired value occurs in time intervals with a constant length which is given by:

$$T_S \leq \frac{2\pi}{20} \sqrt{\frac{L_S\, L_p\, C_F}{\left(L_S + L_p\right)}} . \tag{13}$$

The control delay time T_D of the switching circuit can be expressed by:

$$T_D \leq \frac{I_\delta \left(L_S + L_p\right)}{2\, V_{dc}} - T_S . \tag{14}$$

In a power distribution system, the total power consumption (active and reactive power) and harmonic measurements were carried out. Long time analyses were recorded. The transformer currents and all consumer currents were measured simultaneously with the voltage.

The strongest harmonic voltage and current level was the 5th harmonic. With this data, the validity of the model is proved as in the following lines.

The measured values of the main network harmonic current is fed into the network model and simulated.

Fig. 6, 7 and 8 illustrate significant reduction of the harmonics before and after the compensation.

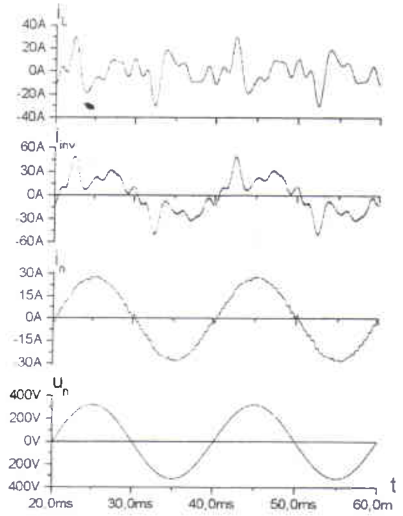

Fig. 6. Performance of the system

Load harmonic current I_L, inverter output current I_{INV}, main network current I_n and main network voltage U_n after compensation

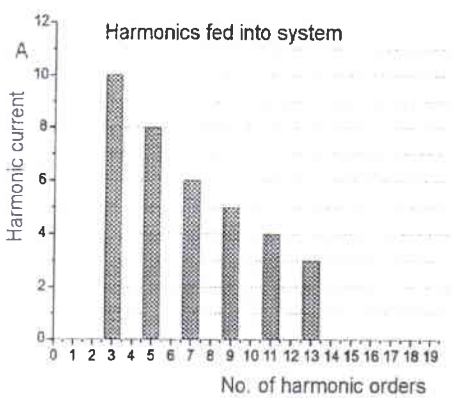

Fig. 7. Harmonic current spectrum without compensation

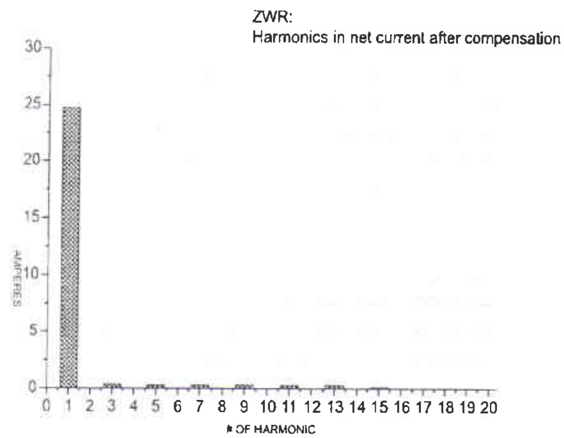

Fig. 8. Harmonic current spectrum after compensation

V. CONCLUSION

In this paper a new method for power factor correction and harmonic current reduction was proposed. The filter circuit parameters were analysed and described. This filter configuration provides an alternative approach to the existing one. According to the test results, the hysteresis control seems to be a more suitable solution because it guarantees a stable operation for the whole system. The proposed approach can achieve a complete elimination of harmonics.

Due to the deregulation, the generation, transmission and distribution will not be in one hand. Therefore, the supply quality may become more critical and this alternative method of controlling harmonics generated by non-linear loads provides a good solution in the industry.

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BIOGRAPHY

İsmail Kaşıkçı, born in Turkey, received two Dipl.- Ing. Degrees from University of Applied Sciences in Darmstadt, Germany and the MPhil degree from Brunel University London.

He has been working as a professional electrical design engineer within the industry for the past 15 years. He is responsible for design and development of electrical power planning, including power distribution networks, transformer stations, protection and control of electrical systems.

He is also a Lecturer at Association of German Electrical Engineers (VDE). His special fields of interest are reactive power compensation and harmonics, design, protection and control of electrical power systems. Additionally, he reviews, proposes VDE and IEC regulations and standards. He is an author of three books in electrical engineering being published in 1999 in German and another three books in Turkish. He is a member of VDE and IEEE.