POWER QUALITY PROBLEMS CAUSED BY POWER ELECTRONIC EQUIPMENT AND POSSIBLE SOLUTIONS

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Abstract: Power quality problems are many and are largely dependent on the system configuration and the system equipment. Power electronic systems present their users with a real problem: the pollution of the power distribution system by currents whose frequencies are harmonics of the system's basic frequency. Since all power electronic equipment use switching devices for power conversion, the quality of the input supply gets affected. Various methods are used to reduce these effects. At the same time, advanced power electronics systems also help reduce harmonics flowing in the power system. This paper presents bad effects of the various power electronic equipment on the quality of input power supply and some solution to overcome them

1. INTRODUCTION

Just ten or fifteen years ago, power quality did not cause a great deal of concern or irritation, because it had very little or no effect on most customer's loads. When, for example, there was a sag, it did not cause problems to induction motors. These motors did not shut themselves off but simply produced a lower output. Customers could notice the effect of a voltage sag only through the dimming of lights.

Mains loads are no longer dominated by heaters, lamps and fixed-speed motors which draw sine-wave currents. More and more equipment presents non-linear and non-resistive loads, and this is particularly true of power supplies. These typically have a capacitor which is effectively charged by the diode bridge with a series of current spike. Similarly, phase control used in lamp dimmers and heater controls chops the mains voltage, again drawing a series of spikes from the mains. These spikes have high harmonic content , which will appear across the ac supply's source impedance and distort the mains voltage. Similarly, high inrush currents can cause large voltage changes at switch on, particularly if the equipment inputs have no inrush current limiting circuits. Such spikes can affect other equipment connected to the mains, and even cause electromagnetic interference with nearby communications equipment. The spikes cause flicker in filament lights, which are particularly sensitive to small voltage changes. They can also interfere with the rapidly increasing range of domestic, commercial and industrial equipment which uses the mains as communications medium[1,2].

The interest in Power quality involves all three parties concerned with the power business: utility companies, equipment manufacturers, and electric power customers. Customers will demand higher levels of power quality to ensure the proper and continued operation of sensitive equipment and processes. Any Power Quality problem could be defined as manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer's electric equipment. Power quality covers several types of problems of electricity supply and power system disturbances. Impulsive transients, repetitive impulsive transients, undervoltages, short interruptions, voltage swells(surges), DC offset, interharmonics, voltage fluctuation(flicker), power frequency variations, oscillatory transients, overvoltages, sustained interruptions, voltage sags(dips), voltage imbalance, harmonics, notching, noise, power frequency variation are all issues related to power quality[3,4].

Due to avoiding the various disturbances the new standards limit very strictly harmonic currents caused by power converters. The recommended practice, IEEE-519, and IEC 1000-3 have evolved to maintain utility power quality at acceptable levels. In order to meet IEEE-519 and IEC 1000-3, a cost-effective and economical solution to mitigate harmonics generated by power electronic equipment is currently of high interest. At the same time, vendors and users of power electronics equipment have been designing solutions to the problem[5].

2. POWER QUALITY PROBLEMS RELATED TO POWER ELECTRONICS

There are many reasons for the growing concern with power quality. One of the most important reasons is development of much sophisticated power electronics equipment used for improving system stability, operation, and efficiency. Because they are so widespread, and the increase of their unit power both in the industrial, service and domestic sectors, equipment based on power electronics have caused more and more problems connected with harmonics. These devices are a major source of bad power quality and themselves vulnerable to bad power quality[6,7].

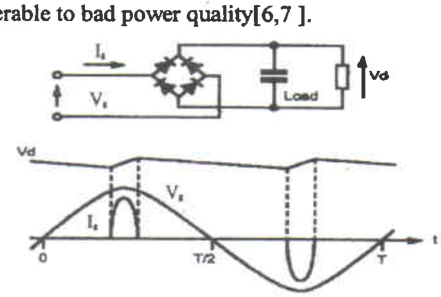

Figure 1. The circuit of diode-bridge rectifier with a filter capacitor and its current and voltage waveforms.

A majority of power electronics applications such as switching dc power supplies, ac motor drives, dc servo drives, and so on, the thyristor and diode rectifiers are commonly used in the front-end of a power converter as an interface with the electric utility. The rectifiers are nonlinear in nature and, consequently, generate harmonic currents into the ac power source as shown in Fig. 1. The nonsinusoidal shape of the input current drawn by the rectifiers causes a number of the problems in the sensitive electronic equipment and in the power distribution network. Generally, individual electric power consumers are responsible for limiting current harmonics because voltage harmonics result from the current harmonics produced by their own power electronic equipment. There are various power quality problems caused by power electronics equipment[3,5].

Harmonics: In practice, real waveforms depart from the sinusoidal as shown in Fig. 2. This may be an unintentional by-product, for example because of the non-linearity of a magnetic circuit or a rectifier, or intentional, for example the use of fast-switching rectangular waveforms in power electronic systems like drives, and logic signals in computers. Fourier transformation allows us to convert non-sinusoidal quantities into series of sinusoidal ones, comprising the fundamental at the underlying repetition frequency, and all multiples of the fundamental, referred to as harmonics. Where the waveform contains fast-changing levels it is very rich in harmonics.

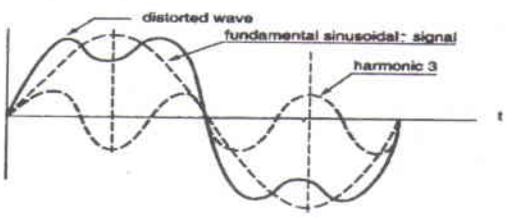

Figure 2. Harmonic Distortion

The harmonic currents depend on the type of the main circuit of the converter as well as on the realization of the control unit. The controlled rectifier will have a higher harmonic content in the load voltage than when the rectifier is uncontrolled. Depending on the pulse number p of the converter, only harmonics of certain orders arise; $h=2k+1$ in single-phase supplies and $h=kp\pm1$ in three-phase supplies. Where k is an integer. Thus in single phase system the most predominant is the 3rd harmonic and in three phase system the most predominant is the 5th harmonic current. The most important harmonics for power system considerations are the lowest orders, particularly the third, fifth and seventh, which at European supply frequencies are 150, 250 and 350Hz. The higher order harmonics usually have much lower magnitudes. It is very unusual therefore for harmonics to cause interference to electronic circuits. Occasionally some kind of resonance in the power system can enhance a higher order harmonic and interference problems may occur, such as noise on telephones.

Interharmonics: Voltages or currents having frequency components that are not integer multiples of the fundamental frequency are called interharmonics. They can appear as discrete frequencies or as a wideband spectrum. The main sources of interharmonic waveform distortion are static frequency converters, cycloconverters, induction motors, arcing devices, and all loads not pulsating synchronously with the fundamental power system frequency. Clearly, the waveform produced by a source with the more steady state frequency is not periodic and even appears asymmetric depending on the interval of observation.

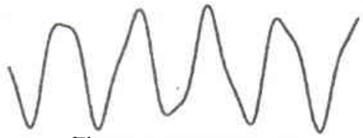

Figure 3. Interharmonics

For interharmonic frequency components greater than the power frequency, heating effects of electrical equipment are observed. From network viewpoint, one of the more important effects of interharmonics is the impact on light flicker.

A variety technique can be used to mitigate interharmonics. The most common technique is through to use passive filters. In addition to use of passive filters schemes a new generation devices is now becoming available. These devices, commonly referred to as active filter, use advanced power electronic techniques to continuously control harmonic and interharmonic level in real time.

Flicker: Loads which can exhibit continuous, rapid variations in the load current magnitude can cause voltage variations that are often referred to as *flicker*. The term *flicker* is derived from the impact of the voltage fluctuation on lamps such that they are perceived to flicker by the human eye. An example of a voltage waveform which produces flicker is shown in Fig. 4. This is caused by an arc furnace, one of the most common causes of voltage fluctuations on utility transmission and distribution systems. Voltage flicker is measured with respect to the sensitivity of the human eye. Typically, magnitudes as low as 0.5% can result in perceptible lamp flicker if the frequencies are in the range of 6-8 Hz.

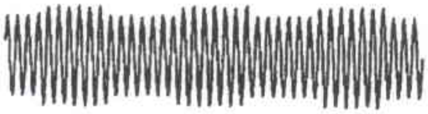

Figure 4. Flicker

Interharmonics are the principle source of flicker. This is often a problem where lightning circuits, particularly using fluorescent lights, are affected. Integral-cycle controlled thyristors and triacs are creates lamp flicker on a 50 Hz supply system. For this reason they are unsuitable as lamp dimmers and such equipment usually consist of phase controlled thyristor and triacs.

Notching: Silicon Controlled Rectifiers (SCR's) are used in electrical controls, we frequently experience line voltage distortion in the form of "notches" when in the waveform. The types of equipment that frequently utilize SCR control schemes and thus experience notching include DC motor speed controls and induction heating equipment.

Notching is a periodic voltage disturbance caused by the normal operation of power electronics devices when current is commutated from one phase to another During this period, there is a momentary short circuit between two phases pulling the voltage as close to zero as permitted by system impedances. Fig. 5 shows an example of voltage notching from a three- phase converter that produce continuous dc current.

Figure 5. Notching

In order to protect the sensitive equipment, we must reduce the notches before they get to that equipment. We will do this through the creation of a simple voltage divider network. The solution is quite economical and easy to install. The normal design practice is to add some inductance in the form of an isolation transformer or line reactor before the drive to decrease the depth and increase the width of the notch.

Noise (EMI or RFI): This is a low-voltage, low-current, high-frequency signal that distorts a specific electric-frequency (50Hz). Noise can be caused by radio frequency interference (RFI), electromagnetic interference (EMI), harmonics from non-linear loads, or other types of electrical interferences. Noise in power systems can be caused by power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies.

Figure 6. Electronic Noise

The SMPS is a source of both EMI and RFI which may appears in the ac supply, as radiated noise or in the output. Control of these various forms of noise is achieved by filtering on both the input and output of the SMPS and by careful screening and attention to the layout of the circuit board.

Noise problems are often exacerbated by improper grounding that fails to conduct noise away from the power system. Basically, noise consists of any unwanted distortion of the power signal that cannot be classified as harmonic distortion or transients. The switching converters supplied by the power lines generate conducted noise into the power lines that is usually several orders of magnitude higher than the radiated noise into free space.

The problem can be mitigated by using filters, isolation transformers, and line conditioners. Generally, the radiated noise is effectively shielded by the metal cabinets used for housing the power electronic equipment.

Electromagnetic Compatibility (EMC) : The expression electromagnetic compatibility (EMC) can be defined as relating to the ability of a device, equipment, or system to function satisfactorily in its environment without either causing intolerable disturbance to other equipment or to itself, being immune to disturbance from electromagnetic interference.

Power electronic equipment with its inherent rapid switching in electromagnetic devices can set up any of the following phenomenon : ac mains disturbance, harmonics, transients, electrostatic discharge, radio-frequency transmissions. The disturbances can be broadly categorized into two groups, those which are radiated through the air in the form of high-frequency radiation and those interferences conducted via the external leads connecting the equipment to the supply source or load.

The other aspect of electromagnetic compatibility, the immunity, is that relating to the ability of equipment to perform satisfactorily in a hostile electromagnetic environment set up by other equipment. Frequently the radiated or conductive interference set up by power switching does itself interfer with its own control electronics, for example causing errors in digital signals and/or control loops. Switched mode power supplies are a prime example of both the generation of and susceptibility to electromagnetic emissions.

Power Factor: In the usual ac system where the current is sinusoidal, the power factor is the cosine of the angle between current and voltage. The rectifier circuit, however, draws non-sinusoidal current from the ac system, hence the power factor cannot be defined simply as the cosine of the displacement angle. In this case, the power factor is defined as the ratio of active power to ($V_{rms}.I_{rms}$). The voltage waveform is normally sinusoidal in nature. But the current waveform contains harmonics. Thus,

Power Factor = $\delta \cos\varphi_1$

Where $\delta = I_{1rms}/I_{rms}$ is input distortion factor , and $\cos\varphi_1$ = input displacement factor. φ_1 will equal the firing delay angle α in the fully-controlled connections that have a continuous level load current.

The power factor will always be less than unity when there are harmonic components in the supply current, even when the current is in phase with the voltage, as in the diode case. An even more common source of low power factor is the rectifier-filter input circuits of power suppliesi converters, and inverters.

Low power factor reduces the load handling capability of your facility's electrical system. It can also overload the electrical equipment within your facility, creating large voltage drops and greater line losses. Most importantly, low power factor increases your total demand charges and your cost per kwh, resulting in higher montly electric bills.

To improve your power factor, capacitors can be placed at either the main point of electrical service or directly on motors or equipment. Also, switched-mode or PWM rectifiers using instantaneous-value control or high-frequency switching is paid to the reduction of current harmonics on the ac side and the realization of unity power factor operation for a given smoothing capacitor on the dc side.

3. SOLUTIONS

It may not be possible to completely solute power quality problems. But, there are various methods for the reduction of the their effects. Legistlation has been brought in many countries to reduce the undesirable effects on power quality due to operation of power electronics equipment.

Reduction of the harmonic content of the voltage to the load is either achieved by more complex circuitry or with the use of filters. The filters are connected on the ac side of the rectifiers in order to reduce the harmonic currents injected into the ac power system. It is possible to reduce the primary current harmonics at converter level itself by injecting harmonic currents of suitable value and phase which cancel out those normally produced by the rectifier. This injection can be effected either via the neutral point of the transformer, whose secondary must be star connected, Zig-zag transformer or via additional transformer windings.

Harmonic filters are composed of line reactors, tuning reactors and capacitors. When properly engineered, harmonic filters can be used to reduce voltage waveform distortions affecting sensitive equipment. In most cases, filters are used to screen out high frequency noise. In practice filters are normally used for the fifth, seventh, eleventh and thirteenth harmonics. If these problems result in unacceptable filter design, İt may be possible to control the harmonics with different types of drives (e.g., 12-pulse or 18-pulse configurations) or electronically with active filters.

In three-phase three-wire devices, the 3rd and multiples of the 3rd harmonic currents will not flows. But, 3rd harmonic currents from three single–phase loads will add-in the neutral, rather than cancel it as is the case of the 50Hz currents. Because triplen harmonics all flow through the neutral conductor, it is reasonable and economical to block the triplen harmonics in the neutral instead of individual phases. Fig. 7. shows a neutral current blocking scheme that connects a third harmonic tuned neutral current filter.

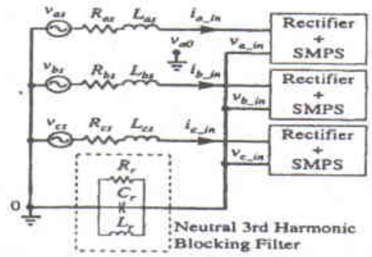

Figure 7. Circuit diagram of an neutral current filter

A special zig-zag cancelling type auto transformer (Zig-zag filter) is practical in canceling triplen harmonic currents from single phase loads. The ZZF employs a three phase autotransformer to cancel the triplen harmonic currents and reduce the upstream neutral currents, as shown in Fig. 8. Because all the triplen harmonic currents are added to the neutral and flowing from load-side back to source-side neutral, the parallel connected autotransformer can provide a zero sequence current path to trap and cancel the triplen harmonics.

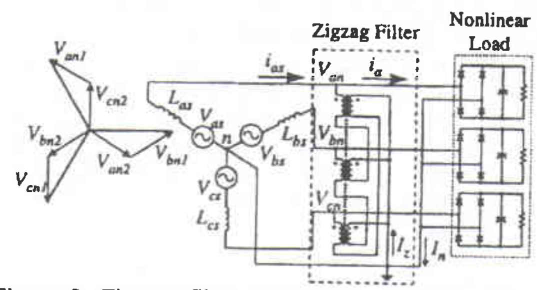

Figure 8. Zig-zag filter connections for three phase nonlinear loads

The pulsating currents drawn by uncontrolled rectifier bridges are often corrected using a high power factor preregulator, which is an uncontrolled rectifier loaded by a boost converter as shown in Fig. 9. The boost converter is controlled to draw a current from the rectifier which has the same shape as the input voltage. The boost converter must process all of the load power.

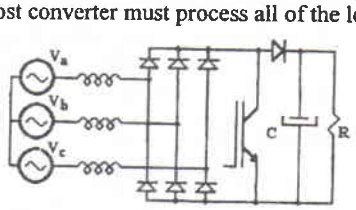

Figure 9. PWM Boost converter

An alternative to minimize harmonic pollution is to replace thyristor and diode based front-end ac-dc converters by PWM converter, Fig. 10. In such rectifiers, a smoothing reactor is replaced on the dc side to provide current source characteristics and, due to the inductive properties of the ac mains, a LC input filter has to be inserted on the ac side to provide a voltage bus and to reduce current harmonic injection due to the PWM operation.

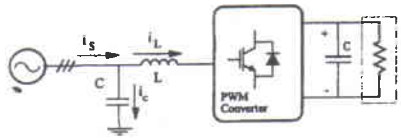

Figure 10. PWM controlled converter

By using PWM the ac current i_L consist of the fundamental sinewave at the ac mains frequency plus large high order harmonic component. The harmonics are filtered by the LC circuit, the current i_s drawn from the electricity company then being near sinusoidal.

A method of converting the nonsinusoidal current into a sinusoidal current in phase with the voltage is to use a PWM converter in parallel with the load, such a converter being commonly known as an active filter or active power line conditioner. Power circuit configuration for the single phase active filter are shown in fig. 11. The active filter is based on a single-phase inverter with four IGBT. The ac side of the inverter is connected in parallel with the other nonlinear loads through a filter inductance. The dc side of the inverter is connected to a filter capacitor. The inverter switches are controlled to shape the current through the filter inductor such that the line is in phase with, and of the same shape as, the input voltage. Turning on S_3 and S_4 will increase is, whereas turning on S_1 and S_2 will decrease it.

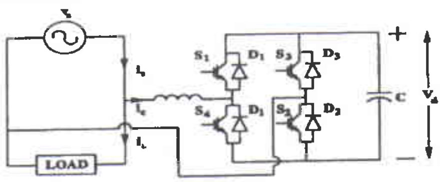

Figure 11. Active filter

To increase input power factor, reduce harmonic current, and achieve fast regulation , the configuration shown in fig. 12. is usually used, where the PFC semistage functions as a current shaper and the dc-dc converter is used for fast regulating the output voltage or current

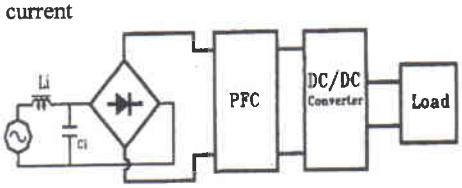

Figure 12. Block diagram of a converter with PFC

A side benefit of PFC would be the reduction EMI and RFI contained in the distorted current wave of ordinary rectifier filter circuits. By eliminating line-current harmonics, PFC could be expected to reduce interference to other equipment on the line, or in the vicinity.

Static var controllers are used to prevent annoying voltage flickers caused by industrial loads such as arc furnaces, which cause very rapid changes in the reactive power and also introduce a fluctuating load unbalance between the three phase.

The most cost-effective way to combat harmonic pollution depends on power level and application. In low-power consumer type applications, where cost considerations dominate, the line reactor is a widely accepted solution. In low power higher-end applications, especially if the equipment is supposed to operate from any line voltage without range switching, the boost rectifier seems the best choice.

In three phase applications, at a power levels below a few tens of kilowatts, diode bridges with boost converters and other less expensiveschemes can be used, while at power levels in the 100 kW range PWM rectifiers of both current and voltage fed types are feasible. Active power filters adopted only when less expensive methods fall short.

4. CONCLUSION

In this paper, some power quality problems caused by power electronics were explained and some possible solutions were presented. In view of the proliferation of the power electronic equipment connected to the utility system, various national and international agencies have been considering limits on harmonic current injection to maintain good power quality. The increased use of power electronic equipment though more efficient has created new problems due to increased harmonic current levels. Appropriate steps must be taken to prevent these from degrading power quality.

REFERENCES

1. MANGAL, M.,"Effects of Power Electronics Equipment on Power Quality", Power Quality'98 Conf. India, 1998, pp. 1-9.
2. McEnnis, M.,"Integrated Function and EMC Testing", PCIM Europe Issue 3/1997, pp. 132-136.
3. MORCOS, M.M., ANIS, W.R.,"Electric Power Quality and Artificial Intelligence", IEEE Pow.Eng. Rev., June 1999, pp. 5-10
4. DOLEZAL,J.,andTLUSTY,J.,"Interharmonics,Voltage Fluctuation, and Flicker in Supply Power System"PEMC'98,Vol.6/7 , pp.100-103
5. REDL,R., TENTI,p., and VAN WYK,J.D.,"Power Electronics' Pollution Effects", IEEE Spectrum, May 1997, pp. 32-39
6. MOHAN, N., UNDELAND, T.M.,and ROBBINS, W.P., "Power Electronics: Converters, Applications and design"John&Wiley ,1995.
7. LANDER, C.W.,"Power Electronics"Mc Graw-Hill Book Comp. 1993
8. LAI,J.S., and Key,T.S.,"Effectiveness of Harmonic Mitigation Equipment for Commercial Office Buildings",IEEE,Ind.App.V.33,No.4,1997,1104-10