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Effects of High Power Electronics Converters on PLC Signals

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Abstract: The harmonics are generated by the switching operation of large power converters, such as Static Compensator (STATCOM), Static Reactive Power Controller (SVC) and UPFC. These harmonics may cover a wide range of frequencies and it can cause problems of interference with communication systems. Power Line Carrier (PLC) system is one of the systems used in transmission of signals for Tele-potations, Tele-tripping, Tele-control and speech communications. The Signal to Noise Ratio (SNR) of the PLC is based on the noise level at the input of the carrier receiver. These effects of harmonics result in overheating, extra losses in electric machines and capacitors; and over voltage due to excited resonance in the power system. The main source of disturbances resulting from harmonics has been proved to be from a high power converter. This problem becomes more complicated when harmonics are originating in many single source. These harmonics can be propagated throughout the entire interconnected power network. The interference due to large power converter will be superimposed on the background noise at lower levels causing it to reduce the SNR to an unacceptable value. This study deals with the analysis of the waveform of the converters and the methods used to reduce the noise imposed on PLC communication signal.

Key words: Power line carner, SNR, converter, harmonic reduction, power transformer frequency

INTRODUCTION

In the recent years, many applications of PLC have been adopted to use the power line as a link for High Frequency (HF) communication systems. One problem of such system is that the noise present in the power line may affect the communication signal. It has been found that the high frequency harmonics produced from high power converters, which cover a wide range of frequencies can cause serious problems of interference with PLC communication systems.

The power converters have been widely used for normal industrial applications. It can be used as a rectifier to produce a high power charger or part of a complicated ac motor drive system. While some systems contain both rectifier and inverter such as, frequency changer, high voltage direct current (HVDC) transmission links, high power frequency changers and the Uninterrupted Power Supply (UPS) systems. The high power switching devices are used for many more applications because of their low cost, high efficiency, controllability and reliability (Bose, 2002; Zajc *et al*., 2004).

The problem may occur in transmission stage as in HVDC (Moyo *et al*., 2002) or in the distribution grid (Geddey *et al*., 1986). The problem becomes more complicated when the harmonics is originating in many single sources. The harmonics can be propagated throughout the entire interconnected power network (Key and Lai, 1998).

The number of equipment affected by noise is increased in accordance with the number of such harmonics-generating sources. The adverse effects of noise in power system are widespread. Many of these effects can be listed as (Shuter *et al*., 1989).

- Interference with PLC systems.
- Interference with telecommunication systems
- The sensitivity could easily appear on the computer system.
- Harmonics can cause interference with protection system
- Interference with TV video signal
- Errors in some measuring equipment such as the induction KWh meters
- Harmonics currents flowing in machines cause heating affects both in the copper and iron losses

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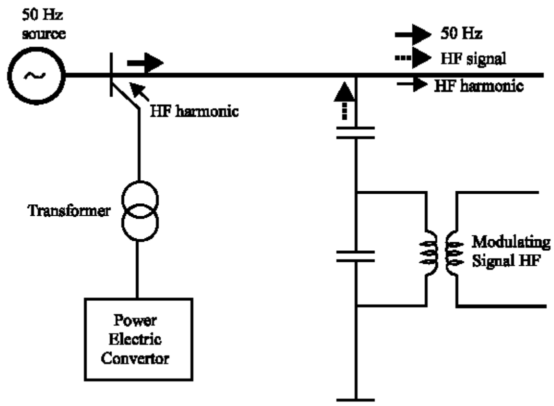

Fig. 1: Connection of PLC and converter to ac line

Figure 1 shows the schematic diagram of the connection of PLC communication system and the power electronics converter to ac transmission line.

This study investigates the effect of high frequency harmonics produced from converters on PLC system, the determination the size of power electronics converter and the level of harmonics at which it start to affect the communication signal. As a result of this study, it has been found that the converter size can not be determined without an actual testing of the converter- transformer system.

SIGNAL TO NOISE RATIO IN PLC SYSTEM

Power transmission lines could be used extensively for the transmission of many forms of communication including telephony, telegraphy, telemetry, telecontrol, protection, internet and various other types of information. This transmission takes place simultaneously with the transmission of electrical energy and without mutual interference. Communication over power lines is accomplished by superimposing carrier- frequencies on the transmission lines. Amplitude-modulation single-side-band suppressed-carrier (AM/SSB/SC) is the most commonly used in PLC systems. Here, therefore lies the task of the carrier-frequency section to transpose the AF intelligence from its (LF) position of 300 to 3700 Hz first to the intermediate- frequency (IF) stage and then into carrier-frequency HF band, which is between 40-500 KHz. The carrier-frequency channels are spaced on a 4 KHz basis.

The noise level at the input of the carrier receiver determines the minimum received signal level is necessary to achieve adequate performance. The minimum SNR considered which is acceptable for PLC circuit, ranges between 25 and 30 dB. SNR is based on noise values within bandwidths corresponding to that of the carrier receiver (Geddey *et al.*, 1986).

CONVERTERS AS SOURCE OF HARMONICS

As power semiconductor devices are suddenly switched on and off at different points on the voltage wave, some harmonics are generated in the system. Consequently, waveforms present in power system are not pure sinusoids, but consist of combination of a fundamental component of 50 Hz and some other high frequency components.

The harmonics generated by the converter appear on both ac and dc sides.

In the ac sides, the converter of pulse number, p generates harmonics principally of the orders of:

$$h = pn \pm 1$$

Where n is any integer.

The converters with pulse number of 6 will produce harmonics in the ac side of the orders 1,5,7,11,13,17,….and for the 12-pulse are 1,11,13,23,25,…. The equipment and loads on the power system are sensitive to the order and magnitude of harmonics imposed by the power converter.

HARMONIC REDUCTION

On the dc- side, the harmonics are of less importance, because the dc- load acts as a filter with high inductive impedance, which minimize the dc- harmonics, since the dc-harmonics is within the sequence of (pn), as there are no transfer of these harmonics between the different voltage levels because of different neutral point treatment. Therefore the reduction of harmonics usually carried on the ac-side only (Brauner and Moraw, 1994).

To overcome the effects of high order HF harmonics, the same methods of reducing the low order harmonics can be used. These methods can be summarized as:

Harmonic filtering: The ac filters are used to minimize the flow of harmonic current into the ac network. This type of HF harmonic reduction is more convenient and cheaper compared with other solutions. There are two types of ac harmonic filters;

I- tuned –filter (TF).
II- high pass filter(HPF).

In a smaller converter, the HPF may be sufficient for the harmonic suppression requirement depending on the converter pulse number (Key and Lai, 1998). Shunt filters usually used in reduction of harmonic currents in the ac –side of the converter.

Active power filter: The active filter uses power electronic switching to generate harmonic current that can reduce or cancel the harmonic currents and the ability to compensate random frequency variations in the current. To overcome the resonance problems, it can be achieved by applying the active filter instead of using passive filters. On the other hand, the active filter systems are costly and require sophisticated control circuits (El-Habrouk, 2000).

High pulse number converter: Two 6-pulse converters can be connected together to form the 12-pulse converter. For simplicity the line-commutated converter has been chosen in this work. Also high pulse number can be achieved by using the multilevel converters.

Generally, the lower the pulse number of the converter, the farther from its sinusoidal ac waveform, the higher its distortion and the greater the harmonics content of the waveform (Shuter *et al.*, 1989).

NOISE LEVEL IN PLC

The harmonic noise generated in a large power converter is a wide band frequency (Brauner and Moraw, 1994).

The aim of this work is to evaluate the effect of HF harmonics (20-400 KHz) produced by large power electronics converter on PLC communication system.

The analysis is performed in the frequency range of 40 K to 500 KHz; this range is used for PLC communication purpose in many countries. It has been found that the power transformer, usually connected to the converter has a big role in reducing the HF harmonics.

An experimental test has been carried out on 25 KVA transformer, when a full load phase current of 38 A, the maximum practical additive noise current is found to be 7.6 mA.

The SNR of the PLC at this noise level can be calculated as follows considering that the signal voltage Vs = 1 Volt.

$$\text{dBm} = 10\text{Log}_{10}\,(P_{plc}/1\text{ mw})$$

where the input impedance of the PLC device is 75 Ω ; therefore:

$$\text{SNR} = 20\text{ Log}_{10}\,(\text{Vs/Vn}) = 4.9\text{ dB}$$

which is less than the minimum acceptable value (Geddey *et al.*, 1986).

The above calculation can be considered only if the losses of power transformer are neglected.

POWER TRANSFORMER FREQUENCY RESPONSE

When the noise current passes through a power transformer it will produce high losses in its core. The transformers at high frequencies have complex periodic structure of distributed coil and winding capacitances. It is not easy to get full information about the winding. However the measurements of such transformer at high frequency have been carried out and gave the practical results of high frequency low voltage error in power transformer as shown in Table 1.

Table 1: Measures of HF low voltage in power transformer with respect to 50 Hz

Freq (KHz)	[%] Error in Vo
40	+9.5
60	+3
80	+3
100	+3
150	+3
200	+3
250	+3
300	-3
350	-25.8
400	-29
450	-29
500	-29

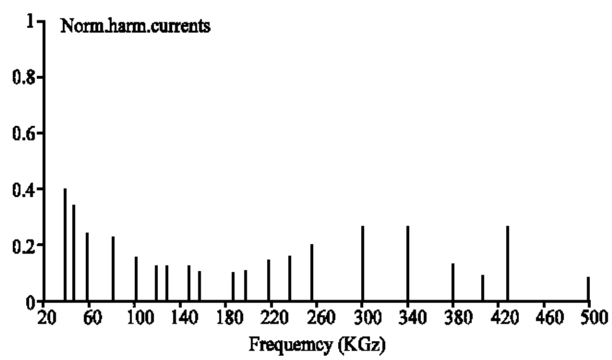

Fig. 2: Normalized HF harmonic currents for 6-pulse converter $\alpha=30^0$

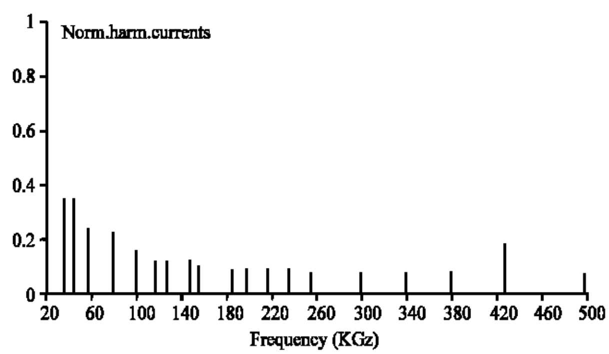

Fig. 3: Normalized HF harmonic currents for 6-pulse converter $\alpha=0^0$

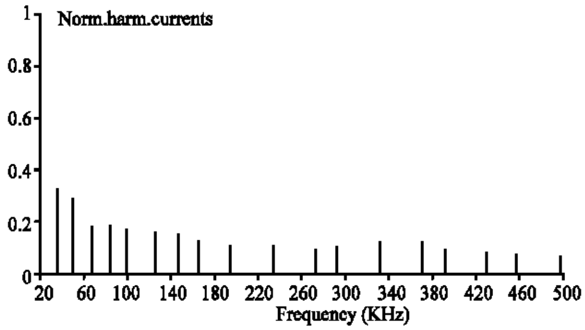

Fig. 4: Normalized HF harmonic currents for 12- pulse converter

The leakage inductance of the transformer with respect to frequency is given approximately as (Evans, 1989):

$$Li = 1 / f^{2.5} \ldots\ldots\ldots\ldots \text{ in H}$$

Where f is the frequency in Hz.

An experimental work has been conducted to test the converter- transformer system at high frequencies. Figure 2 shows the normalized values of HF harmonics (20 kHz to 500 kHz) at delay angle $\alpha = 30°$. Some of on the high frequency harmonics levels have been amplified due to the resonance between the inductance and the stray capacitance of the transformer. It is found that these harmonic levels can be reduced if the delay angle reduces, as shown in Fig. 3 where $\alpha = 0°$ Figure 2 and 3 show the effect of non-linearity of the transformer. Figure 4 shows the reduction of the HF harmonics, when using the twelve-pulse converter.

The above discussion leads to the overall result that; the output of the transformer at HF is non-linear. Due to this reason, it is difficult to determine the maximum power size of a converter, which can give an acceptable value of SNR ratio. This can not be obtained without considering the actual dynamic performance of the power transformer at HF and high voltages, including the losses and stray capacitance.

CONCLUSIONS

The harmonics due to a large power converter covers a wide frequency range with variable amplitudes. The study has been started to investigate the effects of high order harmonics on PLC system, with frequency range near to the frequency used in a commercial PLC devices. It has been found that the effect of a certain noise level of high frequency harmonics on the PLC system causes to reduce the SNR of the system to unacceptable values.

Due to the non-linearity of the power transformer at HF and its inherent stray capacitances, the minimum capacity of the converter, which produces noise level affecting on SNR of the PLC, can not be calculated without considering the actual HF and high voltage performance of the power transformer connected to converter.

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