Analysis of Harmonic Distortion in Non-linear Loads

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Abstract- In this paper, harmonic analysis in non-linear loads such as rectifiers and harmonic mitigation techniques are proposed. To analyse harmonics, there are two types of simulation of non-linear loads. The first method is by using semiconductor devices such as diodes and the other is by using current source parallel with resistor load. Pspice simulation of rectifiers, non-linear load by using fourier series are also presented. Harmonic reduction by tuned filter is also presented.

Keywords- Fourier series, Harmonics, Non-linear loads, Resistors.

I. INTRODUCTION

The specific object of power quality is the pureness of supply including voltage variations and waveform distortion. Harmonics arise whenever non-sinusoidal currents and/or voltages are generated in the power system, they are generally referred to as harmonic distortion. The basic conditions that give rise to harmonic-related problems in power systems are, in brief as follows [1, 2]:

- Non-linear loads;
- Phase imbalance;
- High input voltage or current ;
- Resonance.

The harmonic-related problems caused by the wide spread use of large-capacity nonlinear loads such as rectifiers, inverters and cyclo-converters in industries [3] and on an individual basis, lower capacity ones in modern office-automation equipment [4], lead to the relatively recent creation of a new area in the power electronics field: Power Quality. Power quality is, nowadays, a major topic in the electric-power generation, distribution, and user areas. The use of such types of loads is ever increasing [5].

Harmonic distortion is a form of pollution in the electric plant that can cause problems if the sum of the harmonic currents increases above certain limits. All power electronic converters used in different types of electronic systems can increase harmonic disturbances by injecting harmonic currents directly into the grid. The current harmonics depend on the drive construction and the voltage harmonics are the current harmonics multiplied by the supply impedances.

The odd harmonic amplitudes usually decrease with increasing frequency, so the
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lowest order harmonics are the most significant. Even numbered harmonics are not normally generated by VFD drive systems. The biggest problem with harmonics is voltage waveform distortion. Fast Fourier Transform (FFT) calculation method determines the total harmonic distortion (THD) contained within a nonlinear current or voltage waveform. The total harmonic distortion is the square root of the sum of the squares of the harmonic voltages divided by the fundamental.

**Fig. 1** Harmonic Amplitudes

The rms values of the harmonic components are

\[ I_n = I_1/n \] (1)

where,

- \( I_1 \) - fundamental current, \( n \)-order number of harmonic

**Fig. 2** The harmonic content in a theoretical rectangular current of a 6-pulse rectifier

Figure 3 and 6 show that the line current distortion of single-phase and three-phase diode rectifier respectively. This distorted current can also lead to distortion in the line voltage. By using fourier series, we can calculate total harmonic distortion. Total harmonic distortion in line current in singlephase rectifier is 88.81 percent. But, threephase diode rectifier has total harmonic distortion of 52.84 percent. These results are obtained by using Pspice simulation. Comparison of the line-current waveforms shows that the line current in a single-phase rectifier contains significantly more distortion compared to a three-phase rectifier. This results in a much poorer power factor in a single-phase rectifier compared to a three-phase rectifier.

**Fig. 3** Single-phase diode rectifier circuit[8]

**Fig. 4** Line current distortion waveform of single-phase rectifier

**Fig. 5** Simulation result of line current distortion in single-phase rectifier

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II. HARMONICS IN NON-LINEAR LOAD

Harmonics are one of the major power quality concerns. Harmonics cause distortions of the voltage and current waveforms, which have adverse effects on electrical equipment. Some examples of nonlinear loads are:

- Adjustable drive systems
- Cycloconverters
- Arc furnaces
- Switching mode power supplies
- Computers, copy machines, and television sets
- Static var compensators (SVCs)
- HVDC transmission
- Electric traction
- Wind and solar power generation
- Battery charging and fuel cells
- Slip recovery schemes of induction motors
- Fluorescent lighting and electronic ballasts Simulation of non-linear load is necessary to analyse harmonics. There are two types of simulation of non-linear load. The first method is by using power semiconductor devices such as diodes which are shown in figure 3, 6 and 15 with fourier series and FFT methods. From comparison of singlephase rectifier and three-phase rectifier, line current distortion in single-phase is more harmonics than three-phase rectifier. The second method for simulation of nonlinear load is current source parallel with resistor load. It is illustrated in figure 9.

III. HARMONIC EFFECTS

Harmonics have deleterious effects on electrical equipment. These can be itemized as follows:

A. Capacitor bank failure because of reactive power overload, resonance, and harmonic amplification. Nuisance fuse operation.

B. Excessive losses, heating, harmonic torques, and oscillations in induction and synchronous machines, which may give rise to torsional stresses.

C. Increase in negative sequence current loading of synchronous generators, endangering the rotor circuit and windings.

D. Generation of harmonic fluxes and increase in flux density in transformers, eddy current heating, and consequent derating.

E. Overvoltages and excessive currents in the power system, resulting from resonance.

F. Derating of cables due to additional eddy current heating and skin effect losses. A possible dielectric breakdown.

G. Inductive interference with telecommunication circuits.

H. Signal interference and relay malfunctions, particularly in solidstate and microprocessor controlled systems.

I. Interference with ripple control and power line carrier systems, causing misoperation of the systems, which accomplish remote switching, load control, and metering.

J. Unstable operation of firing circuits based on zero voltage crossing detection and latching.

K. Interference with large motor controllers and power plant excitation systems.

IV. HARMONIC MITIGATING TECHNIQUES

Several different solutions are proposed for harmonic mitigation. The right choice is always dependent on a variety of factors, such as the activity sector, the applicable standards, the power level. Several solutions are relative to Variable Speed Drives, as this type of electrical equipment represents a large part of the installed power in industrial installations and the most significant power harmonic current generators.

A. AC-Line or DC-link Chokes for Drives

They are commonly used up to about 500kW unit power or 1,000kW total drives power. Depending on the transformer size and cabling, the resulting THDv will be ~5%, which is usually well accepted in industrial networks.

B. Multi-pulse arrangement

This solution includes a dedicated transformer directly supplied from the MV network. Standard is the use of a 3-winding transformer providing a 12-pulse supply for one or multiple rectifiers or drives. This limits the power harmonic emission considerably and usually no further mitigation is necessary. Besides, multi-pulse
solutions are the most efficient in terms of power losses. This is usually used for drives above 400 kW, but could also be reasonable for smaller power ratings.

C. Active Front End (AFE)

An Active Front End is a sophisticated electronic circuit connected on the supply side of a Variable Speed Drive. This is the best performing solution concerning harmonic mitigation, limiting the THDi below 5%. All the applicable standard requirements can be met. No detailed system evaluation is necessary, making this solution the easiest to implement.

D. Passive Filter

A passive filter consists of reactors and capacitors set up in a resonant circuit configuration, tuned to the frequency of the power harmonic order to be eliminated. A system may be composed of a number of filters to eliminate several harmonic orders.

E. Active Filter

An active filter is an electronic equipment which injects, in opposite phase, the same harmonic current as drawn by the load, such that the line current remains sinusoidal.

F. Hybrid Filter

A hybrid filter is a combination of a passive filter and an active filter in a single unit. Among them, tuned filter is used to reduce harmonics in line current of nonlinear. It is illustrated in figure 12. It is necessary to consider between reliability and economic.

V. CONCLUSIONS

In this paper, two methods are used to analyse a non-linear load to generate harmonics. From comparison of single-phase rectifier and three-phase rectifier, line current in single-phase rectifier is more distorted than three-phase rectifier. When 20 percent of non-linear loads are presented
in power system, it is necessary to control power quality by harmonic mitigating techniques. Among them, tuned filters are used to reduce harmonics because of economics and usefulness. From the simulation, THD of line current is reduced from 24.95 percent to 1.065 percent.

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