



# EVALUATION OF VARIABLE SPEED DRIVES (VSD) FROM POWER QUALITY POINT OF VIEW. HARMONICS AND POWER FACTOR COMPENSATION

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**Abstract:** This paper deals with power quality aspects when using VSD, such as harmonic and power factor compensation. Practical issues, based on simulation, using dedicated software packages such as Drive size, Matlab and PSim and experimental results are revealed, in conjunction with relevant standard stipulations.

**Key Words:** Harmonics/ Power Quality/ Variable Speed Drives

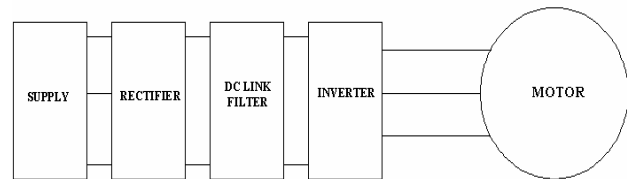


Fig.1 Basic structure of a variable speed drive

## 1. INTRODUCTION

In classical manner, in generated and distributed electric energy, voltage and current must be sinusoidal with predetermined frequency and magnitude. However, nonsinusoidal currents and voltage always exist in electric power systems due to nonlinear elements such as transformers, motors, generators etc. Harmonic pollution in power systems increased in parallel with large proliferation of power electronics devices. One of the most used power electronics device in industry is the variable speed drive due to its benefits. A presence of harmonics in power lines results in greater power losses in distribution grid, interference problems in communication systems, failure of electronic equipments, among other problems.

## 2. BASIC STRUCTURE OF A VARIABLE SPEED DRIVE

A VSD consists of a rectifier, a direct current link, and an inverter (Fig1.). The rectifier converts the input AC supply voltage into a DC voltage. The DC voltage is filtered by the DC link. The inverter converts the DC voltage to an AC adjustable voltage for motor speed control. The rectifier section of a VSD, called "front end", is the part that generates harmonic current into the supply system.

## 3. BACKGROUND ON RELEVANT STANDARDS

The increased understanding of the harmonic pollution has led to the development of standards that promote a shared responsibility between utilities and customers such that utilities are responsible for voltage quality and customers are responsible for not producing excessive harmonic currents

Standards IEEE 519-1992 and IEC 61000-3-6 include recommended limits for harmonic emission. The ultimate goal of harmonic control is to ensure voltage quality. However, IEEE and IEC approach the issue of allocating customer harmonic current production differently.

IEEE 519-1992 provides separate harmonic voltage and current limits. As a part of the share responsibility concept, the utility is generally concerned with meeting the voltage harmonic limits while all customers are responsible for meeting the (appropriate) current limits. Customers connected at higher voltages and customers that are larger with respect to the capacity of the system, are more strictly limited [1].

The IEC 61000-3-6 has developed harmonic limits with a more direct focus on voltage quality. Based on these planning levels, individual customer contribution to the overall permissible voltage distortion is allocated based on the size of customer relative to the capacity of the system and other factors [1].

The standard provides only a single conservative set of possible current harmonic limits and these are only applicable at medium voltage (MV). In this table  $I_h$  is the r.m.s. value of the harmonic component and  $I_L$  is the r.m.s. value of the “agreed power”.

Several caveats must be considered [1] :

- The absolute size of the customer should be small-less than 1MVA
- The relative (to the strength of the system) size of the customer should be small –  $S_L/S_{SC} < 1\%$
- The customer should not have power factor correction capacitors or filters

#### 4. EVALUATION OF VARIABLE SPEED DRIVES (VSD) FROM CURRENT HARMONIC POINT OF VIEW

The current harmonics injected to the power system are functions of the bus impedance and two components of the drive – the size of the DC filter capacitors and the size of the DC inductor or resistor.

For example in Table 1. [2], are presented measurement made on different VSDs from different manufacturers (ABB, Danfoss, Siemens, etc.). The rated power of all drives was 15 kVA . We can observe that the THD depends on the topology of VSD and the load.

#### 5. METHODS FOR HARMONIC REDUCTION

As a result of many researches the main methods of reducing harmonic pollution in the case of frequency converters are:

- Using 6,12,24 pulse rectifiers
- Using active rectifiers
- Using larger DC or AC inductor
- Using active or passive filters

##### 5.1. The use of 6, 12, 24 pulse and active rectifiers

The connections for different rectifier solutions are shown in Fig.2 [3]. The most common rectifier circuit in

3-phase AC drives is a 6-pulse diode bridge. The 6-pulse rectifier is simple and cheap but it generates a high amount of low order harmonics  $5^{th}$ ,  $7^{th}$ ,  $11^{th}$ .

The 12-pulse rectifier is formed by connecting two 6-pulse rectifiers in parallel to feed a common DC-bus. The input to the rectifiers is provided with one three-winding transformer. The transformer secondaries are in  $30^\circ$  phase shift. The benefit with this arrangement is that in the supply side some of the harmonics are in opposite phase and thus eliminated. [3] The major drawbacks are special transformers and a higher cost than with the 6-pulse rectifier.

The principle of the 24-pulse rectifier is also shown in Fig. 6. It has two 12-pulse rectifiers in parallel with two three- winding transformers having  $15^\circ$  phase shift. The benefit is that practically all low frequency harmonics are eliminated, but the drawback is the high cost. [3]

Introducing a rectifier bridge, made of self commutated components, brings several benefits and opportunities compared to phase commutated ones. Like a phase commutated rectifier, this hardware allows both rectification and regeneration, but it makes it possible to control the DC voltage level and displacement power factor separately regardless of the power flow direction.

##### 5.2 Using larger DC or AC inductor

The harmonics of a voltage source AC drive can be significantly reduced by connecting a large enough inductor in its AC input or DC bus [4]. This method to suppress current harmonics is a simple one but it has disadvantages such as the size and weight of the drive or equipment and the voltage drop on the inductor.

In Fig. 3 is a diagram of the simulation carried out PSim and used to study the effect of inductor into the drive. Simulation results are presented in Figures 4.

Table 1. THD<sub>i</sub> 15kVA VSD

THD <sub>i</sub> 15 kW VSD (%)										
VSD	a	b	c	d	e	f	g	h	i	j
Nominal Load	42.4	102.7	68.5	103.2	103.6	59.8	54	112	110	38.9
½ Nominal Load	68.4	114.7	87.4	115	116.4	82.4	79.4	125	126	60.4

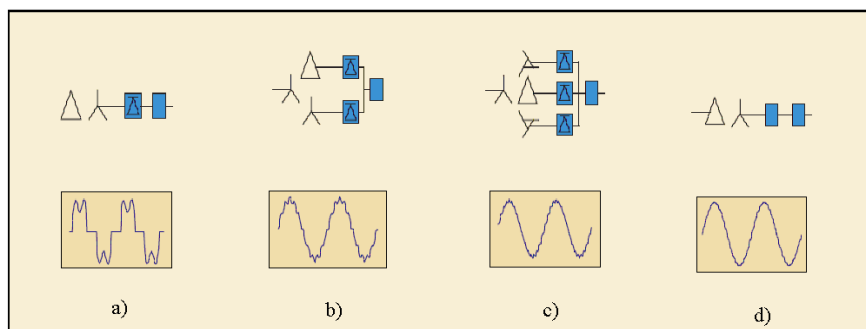


Fig.2 Current wave forms and rectifier configurations:

a) 6 pulse rectifier; b) 12 pulse rectifier; c) 24 pulse rectifier; d) active rectifier;

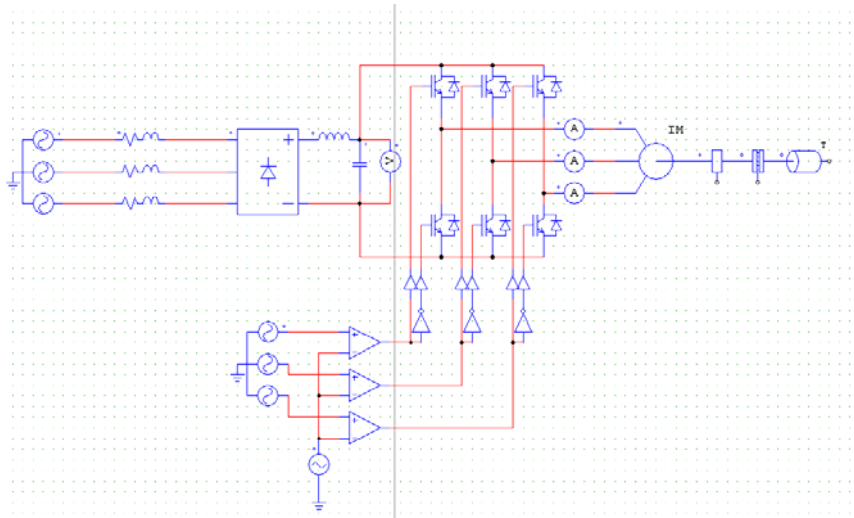


Fig.3 Simulation diagram for the study of AC and DC inductor effects on current harmonic

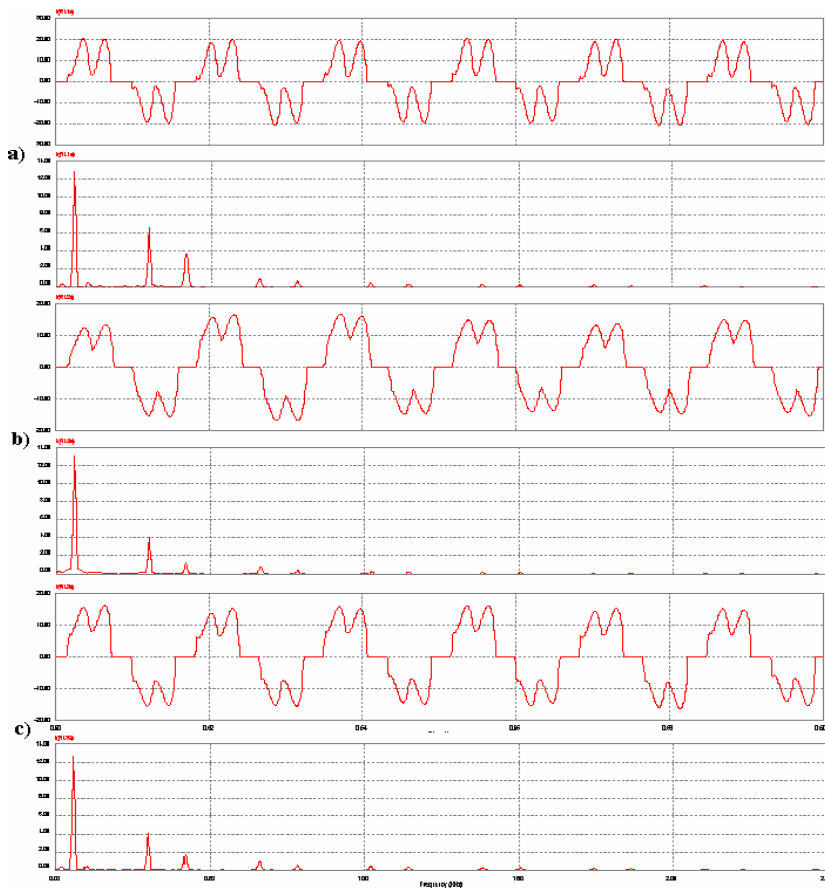


Fig.4 Current waveforms simulation results:

a) without inductor; b) with 1,5mH AC inductor; c) with 1,5mH DC inductor;

### 5.3. Passive Filters

This kind of filters consists of an inductor in series with a capacitor bank and the best location for the passive filter is close to the harmonic generating loads. It has several arms tuned to two or more of the harmonic components which should be the lowest significant harmonic frequencies in the system. Fig. 5 shows a simulation scheme, implemented in Simulink, which describe the effects of passive filters. The passive filters tuned on 5,7,11 and 13 harmonics are connected and disconnected from the network through the switch Brk1.

Simulation results are presented in Fig. 6. Note that by connecting the passive filter to the network THD<sub>i</sub> was reduced from 30% to 3.8%.

### 5.4. Active Filters

A passive tuned filter introduces new resonances that can cause additional harmonic problems. New power electronics technologies are resulting in products that can control harmonic distortion with active control. [5] These active filters, provide compensation for harmonic components on the utility system based on existing harmonic generation at any given moment in time.

## 6. POWER FACTOR COMPENSATION UNDER NON SINUSOIDAL CONDITIONS

Power factor compensation in a network where consumers are non linear must be made with great care because resonance can occur which may cause great inconvenience to the system. To avoid resonance is recommended that compensation be made with detuned filters. Typical detuning frequencies are 204Hz and 189Hz [6]. Using a frequency of 189Hz, allows the connection to the network more consumers distorting than using the frequency 204Hz. These filters also absorb an amount of 10% -30% of THD<sub>i</sub>.

## 7. EXPERIMENTAL RESULTS

The first experimental case show how THD<sub>i</sub> depend on load current; measurements were made at point of common coupling (PCC) of a 130 kW drive from a water treatment plant, Fig. 7 and Fig.8. It should be noted that the current waveform is less distorted when the VSD run at nominal load.

The second experimental case was made to validate the simulation results in the study of AC and DC inductors effects on current harmonics. The current harmonics were generated by a 10 kW VSD at nominal load. In series with the drive a 1,5mH line choke was connected. Figures 9 shows the measurements.

In the third experimental case, a power factor compensator equipment was designed and provided for a water treatment plant, and is used for power factor compensation under non sinusoidal conditions. Three consumers are distorting the current waveform two 90kW and a 36kW VSD used for automation of pumping station for raw water and drinking water. System configuration and measurements are shown in Fig.10. It is noted that the connection of a single 12.5 kVar capacitors battery distort the voltage waveform and the THD<sub>v</sub> became 4.33%. When we connect the 12.5 kVar capacitors battery with the inductor THD<sub>v</sub> remain in normal limits.

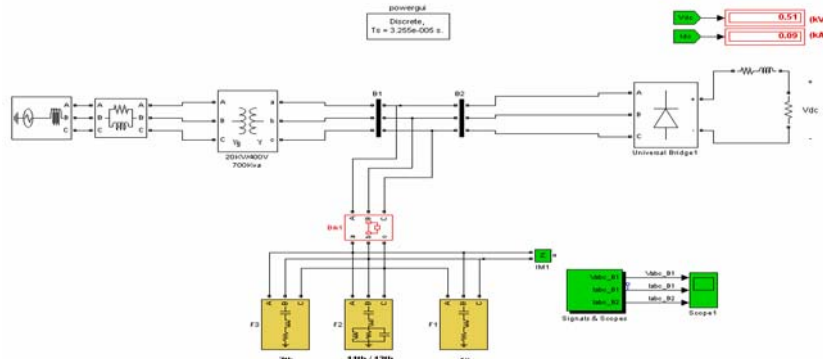


Fig.5 Passive filters simulation scheme

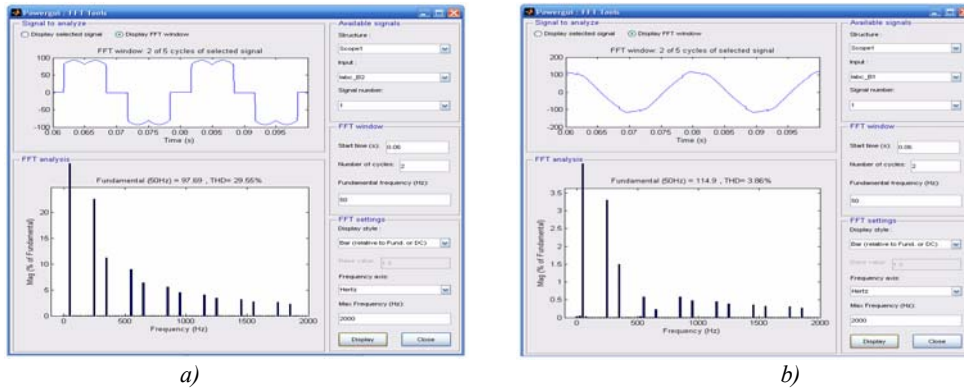


Fig.6 Current wave form and harmonic spectra:  
a) Br1 open; b) Br1 closed

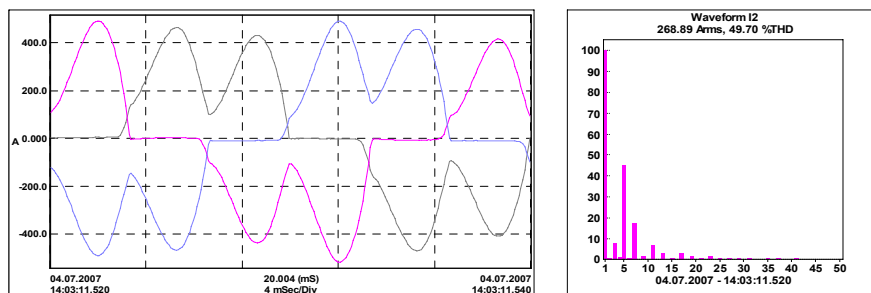


Fig.7 Current waveform and harmonic analysis at nominal load

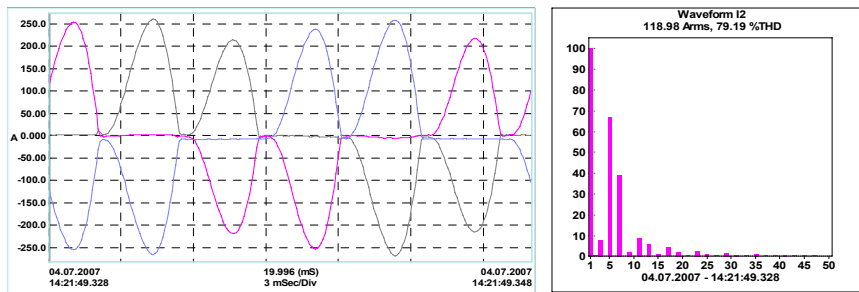


Fig.8 Current waveform and harmonic analysis at half of nominal load

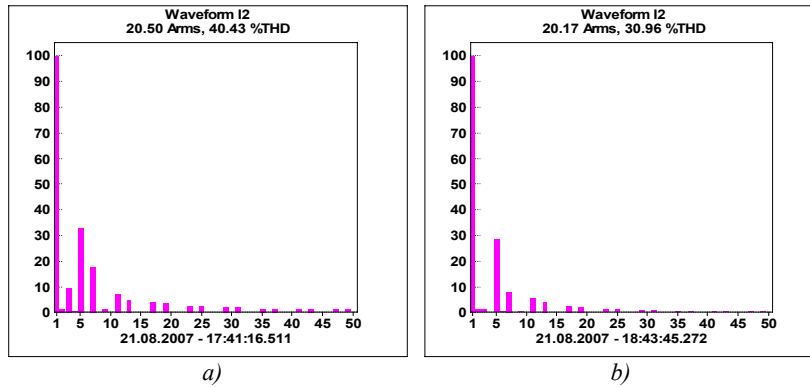


Fig. 9 Harmonic spectra:

a) without line choke; b) with 1,5mH line choke;

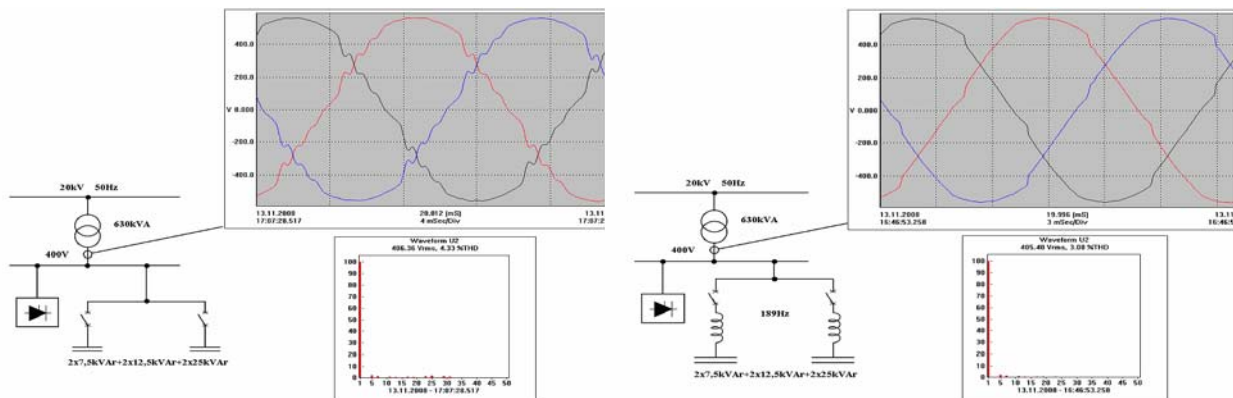


Fig.10 Voltage waveform and harmonic spectra without and with inductor

## 8. CONCLUSION

The VSD represents a current distortion load for the electric supply network. To control harmonics in the electric power systems limitation of  $THD_V$  and  $THD_I$  were adopted which are presented in this paper. There are also presented different harmonic compensation methods with their advantages and disadvantages.

Using capacitors, for power factor compensation, without reactors, can result resonance condition which will lead to high harmonic distortion at the low voltage bus, where the capacitors are connected.

It is important to understand possible harmonic problems and take care that harmonic distortion remains within reasonable limits.

## 10. REFERENCES

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