SMALL AND LARGE AMPLITUDE TRANSIENT RESPONSE ANALYSIS FOR UPS

Ciprian Ionut DUMITRESCU[1], Mihai Octavian POPESCU[2]

This paper focuses on the large amplitude transient response of the UPS in scenarios where the mains voltage disappears at it's peak value and when the load increase it's current consumption at the outputs voltage peak value. Furthermore the small amplitude transient response is shown where the mains voltage disappears near zero crossing and when the load increase it's current consumption at the outputs voltage zero crossing. Method and simulations are explained and conclusions are presented.

Keywords: uninterruptable power supply, voltage stabilization, converter, UPS

1. Introduction

The main benefit given by the UPS is its ability to provide in a matter of milliseconds electric energy when mains power supply fails. In general, they are designed to supply electric energy for a period of 15 minutes at their nominal output power. If the power outage lasts more than a few minutes, then electro-gen units are started to ensure continuous power supply for long periods of time [1][3].

Given this, we have to understand how the load is affected right at the time of mains power supply outage in scenarios where there is small and large amplitude transient response. In some situations, this scenario happens often and the effects on the load can translate into shorter lifespan and improper functioning. These effects have a greater impact on sensitive devices like personal computers, servers or laboratory equipment [4][2].

One of the key points in determining a way to minimize or to remove the effects of the input voltage variation for the load is to understand how the transient response influences the output voltage [7].

[1] PhD student, Faculty of Electrical Engineering, Dept. MAECS, University POLITEHNICA of Bucharest Romania, e-mail: ciprian.i.dumitrescu@gmail.com

[2] Prof., Faculty of Electrical Engineering, Dept. MAECS, University POLITEHNICA of Bucharest, Romania

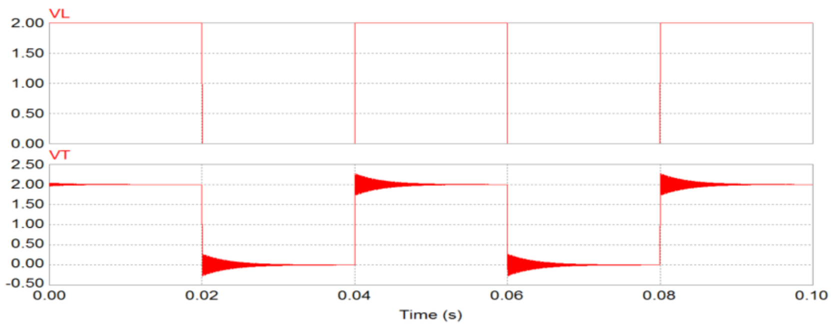

Fig. 1.VL Ideal square wave / VT Effects of transient response

An important aspect is how often the transient response appears throughout the normal functioning of the devices powered by the UPS. In Fig. 1 it is presented an example of a transient response for a square wave [6]. VL is the ideal square wave and VT is the square wave with the effects of a transient response each half cycle. Another source of distortions for the voltage could be the variable load itself.

If the current drown by the load varies abruptly, then the voltage and current waveforms are modified accordingly and this transient response has effects for the UPS itself [13][14].

2. Materials and Methods

Simulations where realized in PSIM program under WINDOWS operating system. Parameters for the simulation are presented for a load with a power factor of 0.7 and the electronic structure presented in Fig. 2.

This structure is voltage and frequency dependent and it has been chosen because it combines effects of the transient response for On-Line/Double conversion, Line interactive and Offline categories of UPS.

First it has been verified the transient response given by the input voltage disappearing when it crosses zero and when it reaches its peak value.

The second part represents a simulation where the mains voltage is present at all times, but the load doubles its current consumption at the zero crossing of the input voltage and at its peak value.

Inverter functions at a frequency of 50kHz and the boost converter is set to raise the input voltage if the inverter output peak voltage drops below 320V.

For simplicity, the battery charging circuit, inverter and boost converter control circuits are not being presented.

3. Results

Most of the UPS systems used for powering small loads have an electronic structure similar with the one presented in Fig. 2. This is because of its price-performance ratio, which makes it a good solution for multiple cases. In this simplified schematic, T2 transistor enters conduction phase when mains voltage,

VAC drops below a predefined value. Only in this case the UPS switches the powering of the load from mains to battery pack. When mains voltage raises above the predefined value then T2 transistor decouples the load from battery pack back to mains supply. This is the normal functioning state of the UPS.

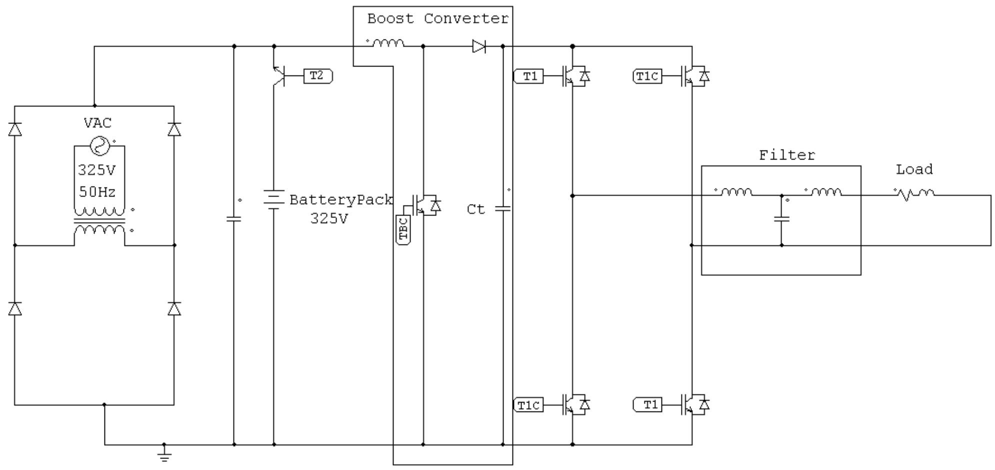

Fig. 2. Simplified schematic of UPS used for simulation

If the load raises its current consumption or if the mains input voltage drops then the boost converter starts to raise the inverter supply voltage to maintain a constant output voltage.

A. Constant load analysis

This simulation takes into account that the average value of the current drown from the power supply is constant throw-out the input voltage variation.

A.1 Small amplitude

In Fig. 3 it is presented the input voltage Vi, output voltage Vs.

As it can be seen the mains power supply disappears right at the time of zero crossing, T = 40ms, and the UPS transfers the load from mains to battery supply. This creates an output voltage variation that is seen by the load as a small voltage drop.

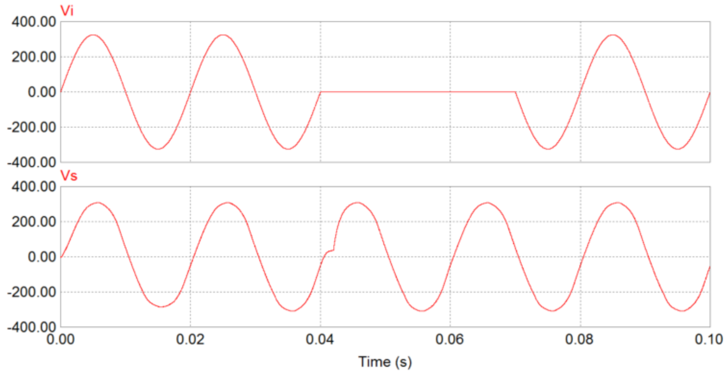

Fig. 3. Input voltage Vi / Output voltage Vs

In Figs. 4a, 4b it is presented the Fast Fourier Transform for the output voltage and current.

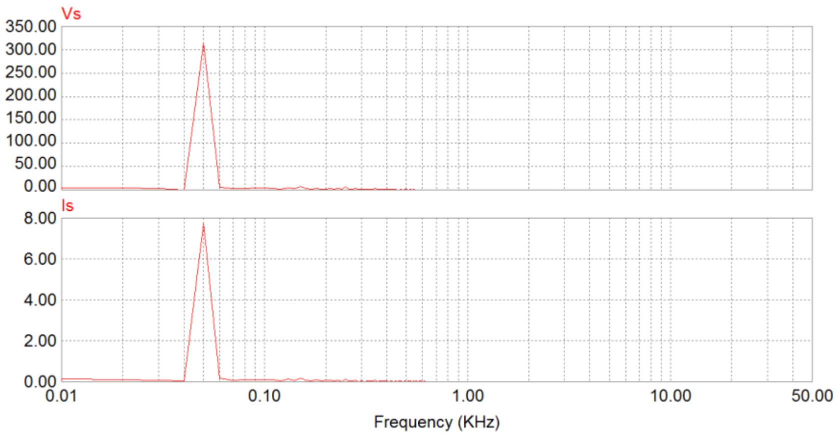

Fig. 4a. Output voltage Vs FFT / Output current Is FFT

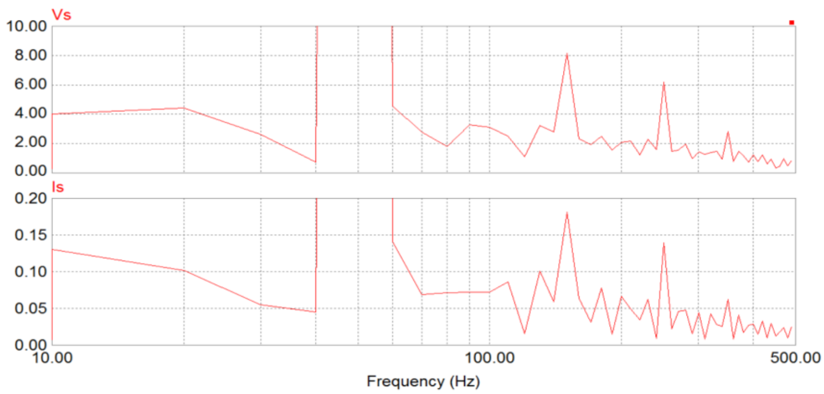

Fig. 4b. Output voltage Vs FFT / Output current Is FFT between 10-500 Hz

The current is affected as much as the voltage in regard to amplitude of spectral components based on its main value. These are unwanted and can have a negative impact on the load. They are present only for the duration of the transient response which lasts approximately 2ms. In time, especially after numerous situations when this happens, they can contribute to the shortening of the loads lifespan.

Fig. 5 shows the input voltage and VCt capacitor voltage.

When the input voltage disappears, the Ct capacitor is discharged, and this reflects in the voltage drop for the load. This cannot be eliminated through output filter design, but it can be reduced.

For this simulation, the capacitor has a value of 100μF and it is being discarded only when mains voltage disappears. An improper capacitor value would have resulted in higher variations, thus is important to take into account not just the normal operations of the UPS but also the transient response associated with power outages or voltage drops [11].

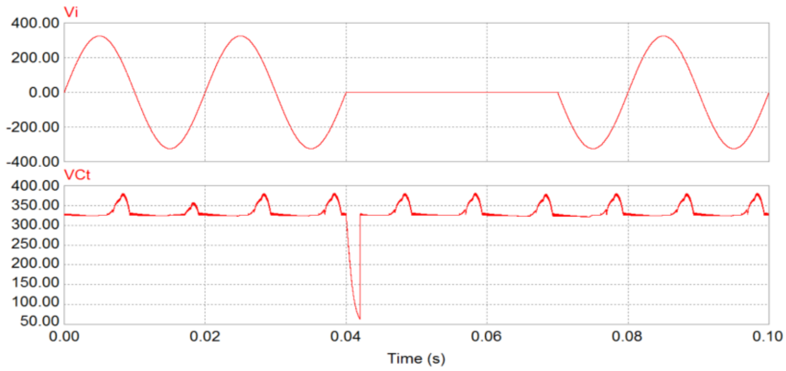

Fig. 5. Input voltage Vi / Capacitor voltage VCt

At T = 70ms the mains voltage reappears and there is no transient response seen by the load. In this situation, the capacitor is not being discharged more than in normal operation because the boost converter is maintaining the output voltage and when mains supply reappears the boost converter lowers its conduction time to a predetermined value [2].

A.2 Large amplitude

It is presented in Fig. 6 the input and output voltage for the large amplitude response and in this case the load is affected when the input voltage disappears but also when it reappears. This is not present for the small amplitude response because the boost converter is able to correct the output waveform quality better when the variation has small values. From the FFT in Figs. 7a, 7b we can see a powerful rise in the spectral components both for voltage and current. Compared to the small amplitude simulation the spectral components is almost double in value for the same parameters.

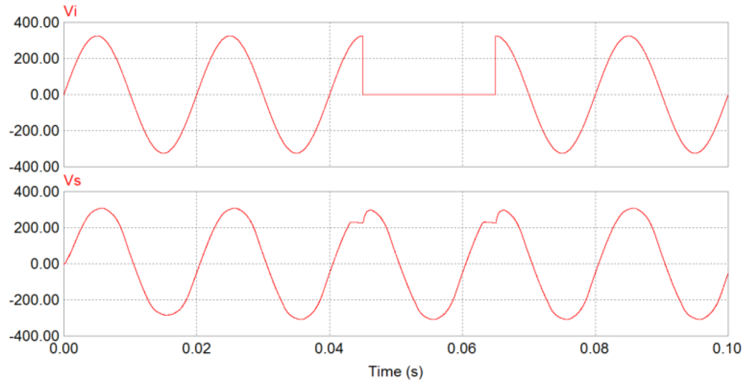

Fig. 6. Input voltage Vi / Output voltage Vs

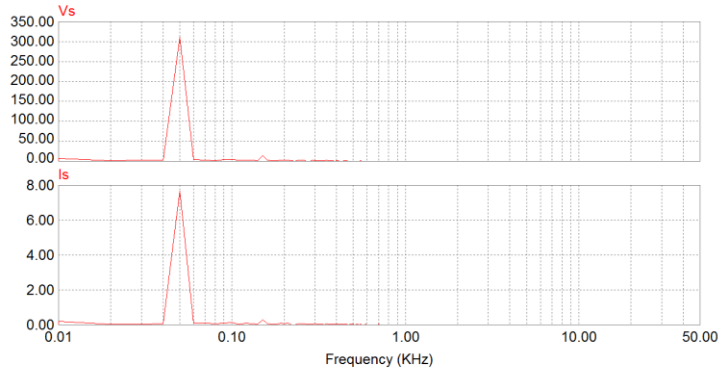

Fig. 7a. Output voltage Vs FFT / Output current Is FFT

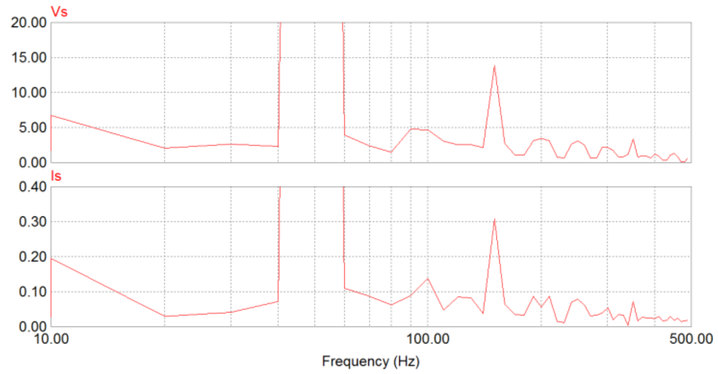

Fig. 7b. Output voltage Vs FFT / Output current Is FFT between 10-500 Hz

B. Variable load analysis

This simulation takes into account that the average value of the current drown from the power supply is increasing and there is no input voltage variation. The UPS functions in normal operation.

B.1 Small Amplitude

In Fig. 8 it is presented the output voltage and current.

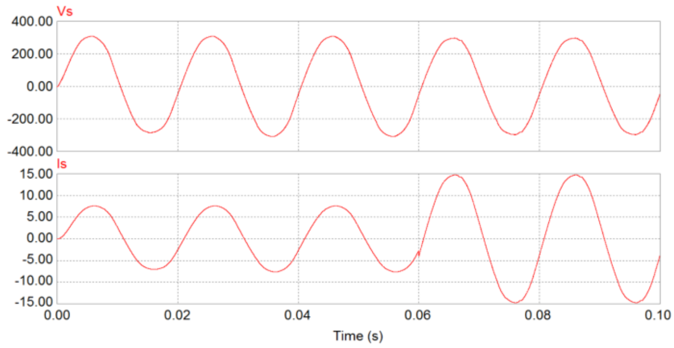

Fig. 8. Output voltage Vs / Output current Is

At T=60ms the load raises its current consumption to double of its previous value. There is no output voltage variation because the boost converter raises the output voltage accordingly. There is a current spike of approximately 1A. Looking at the FFT for the current, Figs. 9a, 9b, there are increasing spectral components from 50Hz to 500Hz [3][8].

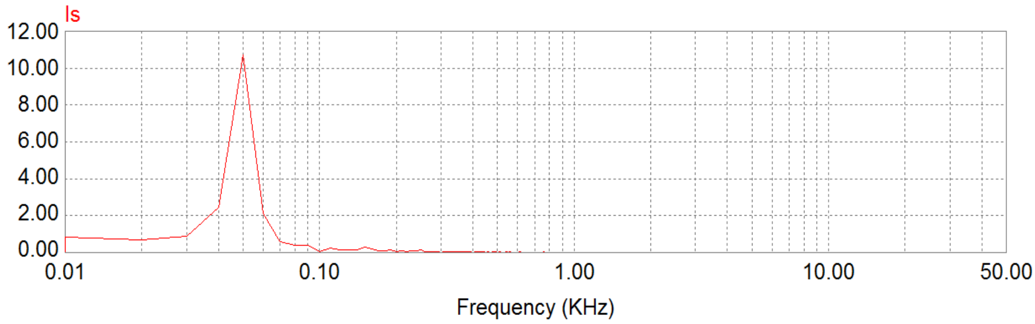

Fig. 9a. Output current Is FFT

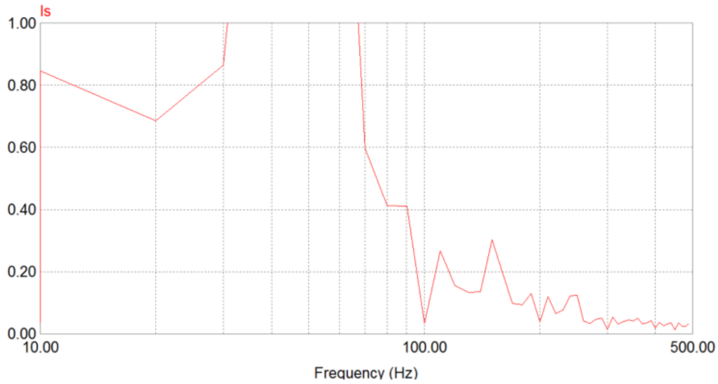

Fig. 9b. Output current Is FFT between 10-500 Hz

This transient response is directly proportional to the current variation. A three times increase in current would result in a 3A spike. As it can be seen in Fig. 10 the capacitor voltage VCt has no variation, thus the load itself is the one responsible for the transient response.

This type of variation is more commonly seen in applications as opposed to the mains power supply outage, and its frequency of apparition is very high in some scenarios [10].

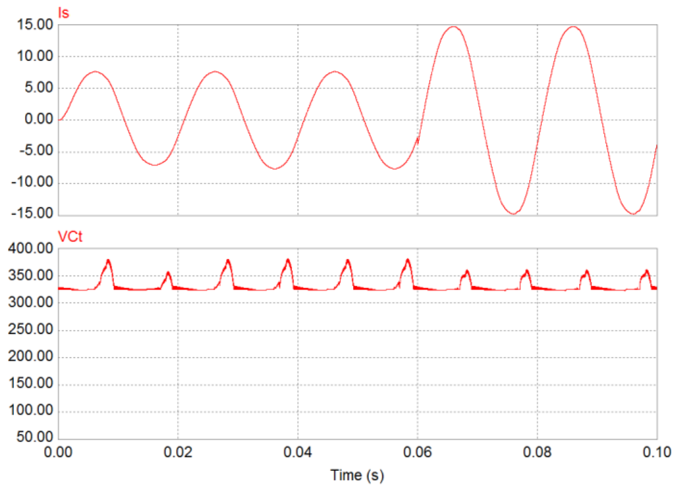

Fig. 10. Output current Is / Capacitor voltage VCt

B.2 Large Amplitude

In Fig. 11 it is presented the output voltage and current when the load doubles its current consumption when the output voltage is at its peak instantaneous value.

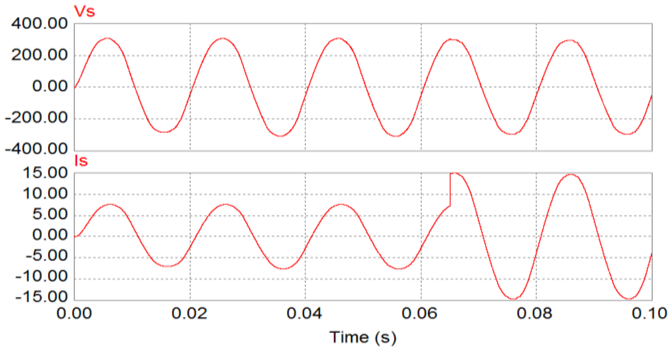

Fig. 11. Output voltage Vs / Output current Is

The variation in this case is a current spike of 7.5A. In this situation, the transient response is not proportional to the average current variation but to the difference between final current peak value and initial current peak value. A three times increase in current from a peak value of 7.5A would result in a 15A current spike.

The boost converter is able to maintain the output voltage within standard values even though the current variation is higher [15]. It is important to note that improper dimensioning would result in output voltage variation [9][5].

In Fig. 12 the capacitor voltage is not being discharged meaning that even a more powerful transient response given by the load is supported in nominal parameters by the UPS.

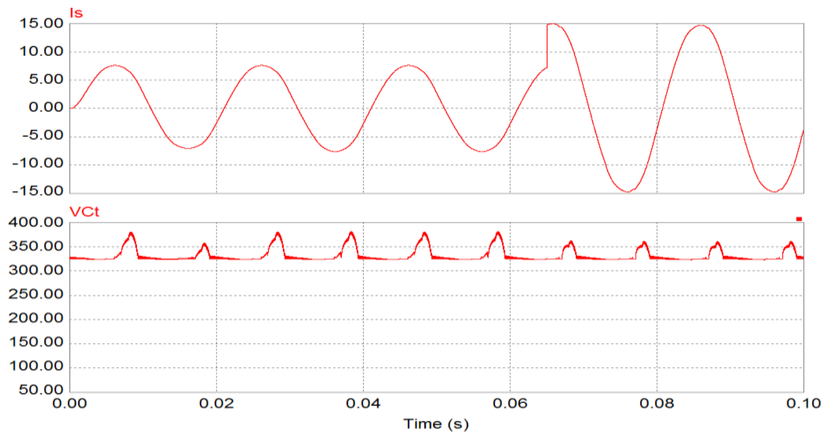

Fig. 12. Output voltage Vs / Output current Is

The output current FFT from Figs. 13a, 13b shows increasing spectral components just as in small amplitude scenario, from 50Hz to 500Hz, but with much higher amplitude.

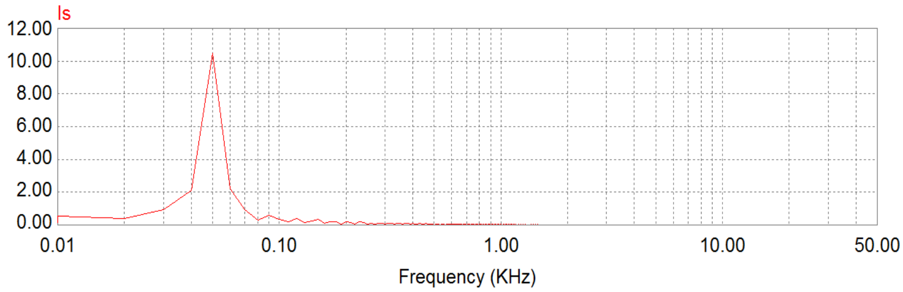

Fig. 13a. Output current Is FFT

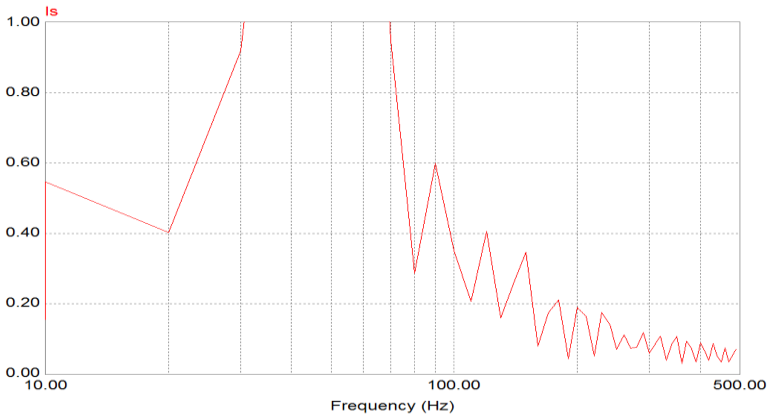

Fig. 13b. Output current Is FFT between 10-500 Hz

6. Conclusions

It is important to understand better the transient responses within such a complex structure, as the UPS, to be able to design and propose configurations with high output waveform quality. Because of their high frequency of occurrence their effects can have a negative impact in a short amount of time.

Research at this moment is concentrated on improving output quality rather than extending installed power. The UPS is used more and more because of its underlying advantages and the benefits they give.

This paper has shown a direct correlation between transient response amplitude and the instantaneous value of the voltage. UPS structures implement an electronic zero-crossing voltage detector to compensate for the unwanted effects of the response, but these circuits cannot detect when the input voltage will disappear, instead they are useful when the input voltage reappears.

As it has been shown, the transient response is at its lowest when the load increases its current consumption and when the voltage disappears and right at the time of zero crossing. Electrical power systems offer better output voltage characteristics.

Small period voltage variations can have a big impact if their frequency of occurrence is high and this usually happens when there is poor designing or when the device advances in its lifetime.

Another important aspect of an UPS is that it can offer control over the output voltage/current waveform quality. They can be used as backing up the mains electric power while also providing stabilization and filtering of electric energy, guaranteeing a certain quality at its output. This in turn counts for a longer lifespan of powered devices, especially devices used in a constant 24/7 functioning mode and for this reason the transient response given by the variable load has to be taken into account.

The output filter on an UPS has a cut-off point of 20 or 30 times lower than the PWM frequency. If the PWM circuit operated at 150kHz, the filter would have a cut-off frequency of 3 to 5kHz. The UPS is able to withstand a variable current drawing load. It has been shown that the response in this situation introduces unwanted spectral components. If the output filter is designed correctly then this transient response can be considered as being negligible. If the cut-off frequency of the filter is well below the PWM frequency then the output quality of the wave is greatly improved, and the cost of the filter is higher.

R E F E R E N C E S

[1]. *Dumitrescu C.I., Popescu M.O.,* Characteristics of different UPS Topologies, Electrotehnica, Electronica, Automatica (EEA), 2016, vol.64, no.4, pp. 102-105, ISSN 1582-5175.

[2]. *Dumitrescu C.I., Popescu M.O.,* UPS Voltage Stabilization by Boost Converter Implementation", in Electrotehnica, Electronica, Automatica (EEA), 2016, vol.64, no. 2.

[3]. *Dumitrescu C.I., Popescu M.O.,* Characteristics of UPS transient response, International Symposium on Fundamentals of Electrical Engineering (ISFEE), 2016, ISBN: 978-1-4673-9575-5

[4]. *Matei G., Lingvay D., Spafiu P.C., Tudosie L.M.,* Electric consumers influence on powere quality – case analysis, IEEE.

[5]. *Safari. A, S. Mekhilef,* Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter, IEEE Trans. on Ind. Elect., Vol. 58, Issue 4, pp: 1154 - 1161, 2011.

[6]. *Prudenzi A.,* A novel procedure based on lab tests for predicting single-phase power electronics-based loads harmonic impact on distribution networks, Power Delivery, IEEE, Vol. 19 (2), 2004.

[7]. *N. Femia, G.Petrone, G.Spagnuolo, M. Vitelli,* Optimization of Perturb and Observe Maximum Power Point Tracking Method, IEEE Transactions on Power Electronics, Vol. 20, No. 4, July 2005.

[8]. *Balasz G. Gy., Hortvath M., Schmidt I.,* Comparison of Sinusoidal and Resistive Modulation Strategies for Single Phase Four Quadrant Converters, Electrotehnica, Electronica, AUtomatica (EEA), Vol. 58 (3). 2010.

[9]. *Edgar Campos Furtado, Luis Antônio Aguirre, Leonardo A. B. Tôrres,* UPS Parallel Balanced Operation Without Explicit Estimation of Reactive Power—A Simpler Scheme,

IEEE Transactions on Circuits and Systems—II: Express Briefs, vol. 55, no. 10, october 2008.

[10]. *Omar Abdel-Rahim, Mohamed Orabi, Emad Abdelkarim, Mahrous Ahmed, Mohamed Z. Youssef*, Switched Inductor Boost Converter for PV Applications, APEARC, South Valley University, Egypt, 2012.

[11]. *H. Bai, F. Wang, J. Xing.* Control Strategy of Combined PWM Rectifier/Inverter for a High-Speed Generator Power System, 2nd IEEE Conference on Indrustial Electronics and Applications, 2007.

[12]. *B. R. Lin and F. Y. Hsieh,* Soft-switching zeta–flyback converter with a buck–boost type of active clamp, IEEE Trans. Ind. Electron., vol. 54, no. 5, pp. 2813–2822, Oct. 2007.

[13]. *Li Song, YE Manyuan,* Hybrid Frequency Carrier Modulation Technique for Hybrid Cascade Multi-level Inverter, High Voltage Engineering, 2015, 41 (7): 2378-2383.

[14]. *Yi Wang, Heming Li, Xin Chun Sh.* A novel carrier based PWM strategy for hybrid multilevel inverters, Proc. IEEE Power Electronics Spec. Conf., 2004.

[15]. *Mohamad Reza Banaei, Farhad Mohajel Kazemi, Mohammad Reza Jannati Oskuee*, New mixture of hybrid stacked multicell with half-cascaded converter to increase voltage level, IET Power Electron. 6 (7) (2013) 1406-1414.