DC-Source with Minimal Influences on the Supply Network

Vaclav Kus, Martin Pittermann, Jiri Fort
Dept. of Electromechanics and Power Electronics
University of West Bohemia
Pilsen, Czech Republic
kus@kev.zcu.cz, pitterma@kev.zcu.cz, fort@kev.zcu.cz

Abstract – **This paper describes the design of special high power DC-source 110V/1kA. The emphasis was taken to the issue of the negative impact minimizing of DC source on power supply network from low-frequency interference point of view. The paper contains the simulation model of proposed DC source and simulations of two connections. The simulation results are verified by measurements on experiment.**

Keywords - Power converter; low-frequency EMC

I. INTRODUCTION

Additional installation of high-power device into existing installations can bring big problems in terms of its negative impact of this device to the supply network. Typical example is additional installation of special device for high-power experimental device into standard installations in building of research institute or of technical universities. The use of high power rectifiers and assessing their impact on the power supply system is currently no longer a problem [1-6]. These cases thus correspond to contradictory combination of installation of high-power converter (as in industry) in environment of the strict requirements for low interference (as in the home and public sector).

II. THE BASIC VARIANTS HOW TO REALIZE OF POWER CIRCUIT

Special power source for this experimental heating device must meet the following special requirements:

- Maximal output power of this source is up to 1kA and 110V (i.e. approximately nominal output power 110 kW).
- Possibility of the quickly regulation (full range 0% to 100% during some milliseconds).
- DC-output with minimal ripple of output DC-current.
- Low interference to supply network and to other devices.
- Long-life and maintenance-free.
- Small weight, small dimensions, low cost.
- Only one unique special single-purpose device (requirement to minimize the development and attempt to use standard parts).

These requirements can be met using these variants of power circuit:

- Non-controlled rectifier with special regulation transformer.
- Non-controlled rectifier with regulation on AC-side of rectifier (using cheap additional AC thyristor converter).
- Controlled rectifier (or half-controlled rectifier).
- Non-controlled rectifier with regulation on output DC-side (step-down buck converter with IGBT).
- Combination of these variants – with configuration consist of the combination of some number of non-controlled subsystems (with possibility to switch on/off independently) and one subsystem with possibility to regulation
- Other method – for example with energy storage elements (see for example [4]).

It was made the simulation and measurement for the special configuration of rectifier and its transformer for purpose to achieve minimization of the negative influence to supply network (and to achieve minimization of ripple of output DC-current).

III. THE METHOD OF THE COMPARING OF VARIANTS OF POWER CIRCUIT

The comparing of these variants of power circuits was realized with using of the simulation in Matlab/Simulink/Plecs. These results of simulation were compared in regime of full output power and in some regimes with reduced output power (for example output voltage 50% and output current 50%). Next pictures show some interest results of this simulation. Pictures show input current (time behavior and its frequency spectrum, THD and other parameters).

IV. SIMULATION

A. Non-Controlled 6 –pulse Rectifier

The basic circuit diagram of the converter is on Figure 1. With regard to the next steps the connection **Yy0** was chosen. Buck converter in DC circuits can change current to correspond to the thermal requirements of the appliance. With regard to wiring in the existing network there is important to monitor the shape of current drawn from the network and perform harmonic analysis. It is also necessary to assess the size of the load on the monitored variables. In accordance with the standard there is also appropriate to monitor the overall coefficient of current distortion THD_I.

Current waveforms for full and reduced power are shown in Figure 2a, respectively 2b, harmonic analysis

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of these currents are in Figure 3a, respectively 3b. Because the single-wave voltage source is assumed, there are mainly characteristic harmonics in the spectrum. For connection with one transformer the waveform is 6-pulse (i.e. p=6) and the orders of characteristic harmonics are h=1,5,7,11,13...:

$$h = k \cdot p \pm 1 \tag{1}$$

From the waveforms and the harmonic analysis it is obvious that the current is very smooth at full power and with respect to the commutation it is also very little distorted. For small load the current is more distorted. The results of harmonic analysis correspond to the amplitude law (2) :

$$I_h = \frac{1}{h} \cdot I_1 \tag{2}$$

B. *Non-Controlled 12 –pulse Rectifier*

The next part shows the results of simulations and harmonic analysis for the case of 12-pulse connection of rectifier (i.e. p=12). For these purposes the 3-windings transformer in **Yy0d11** connection was modeled. Circuit diagram is shown in Fig. 4, the waveforms and FFT results are shown in Fig. 5 and 6.

Circuit diagram is shown in Fig. 4, the waveforms and FFT results are shown in Fig. 5 and 6. The advantage of 12-pulse connections is evident from the waveforms. Harmonics, which now do not correspond to equation (1), here for example 5th, 7th, 17th, 19th, etc. harmonics are almost zero.

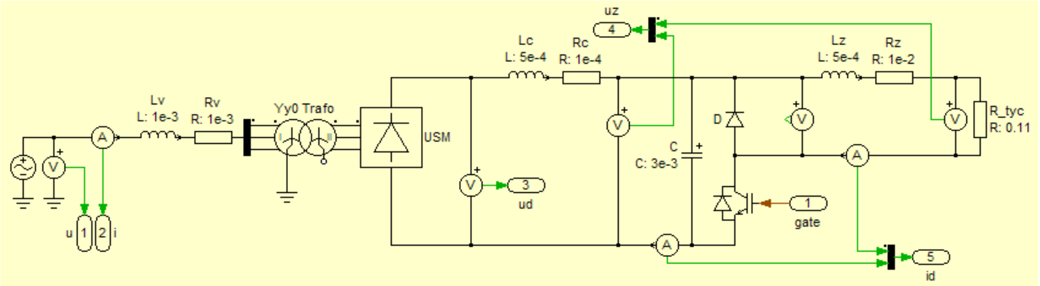

Figure 1. Diagram of non-controlled 6-pulse rectifier, buck converter on DC-side and additional inductance

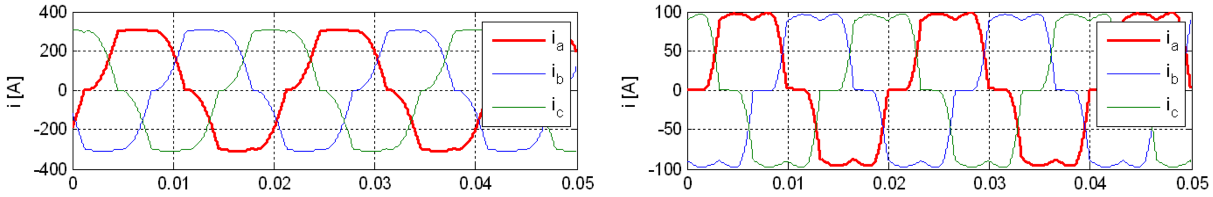

Figure 2. AC current: a) with nominal load, b) AC current with reduced load

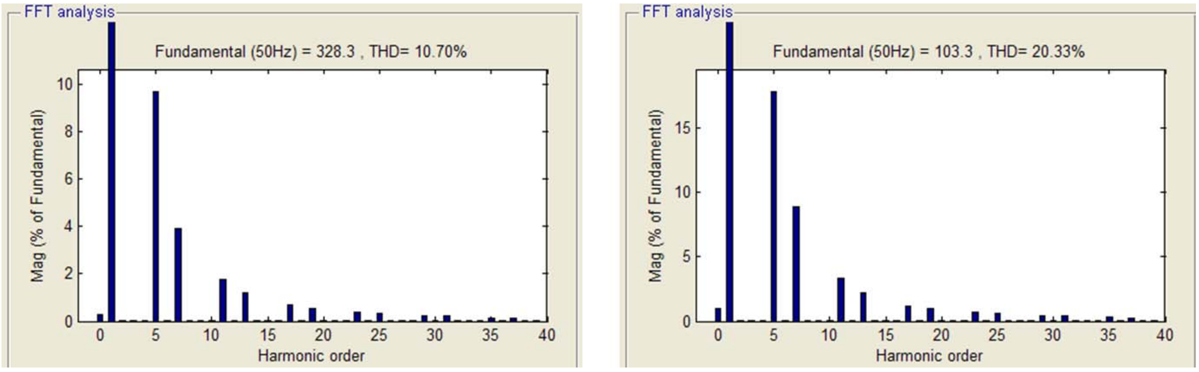

Figure 3. FFT results of input currents: a) full output power, b) reduced output power

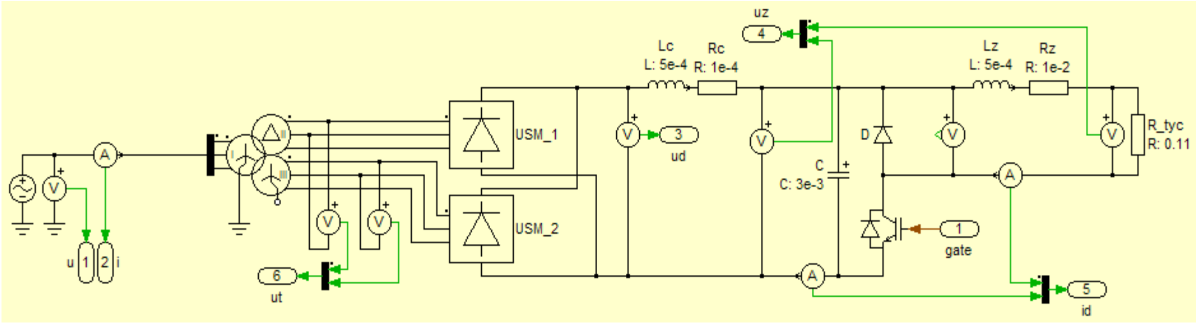

Figure 4. Diagram of non-controlled 12-pulse rectifier, buck converter on DC-side and additional inductance

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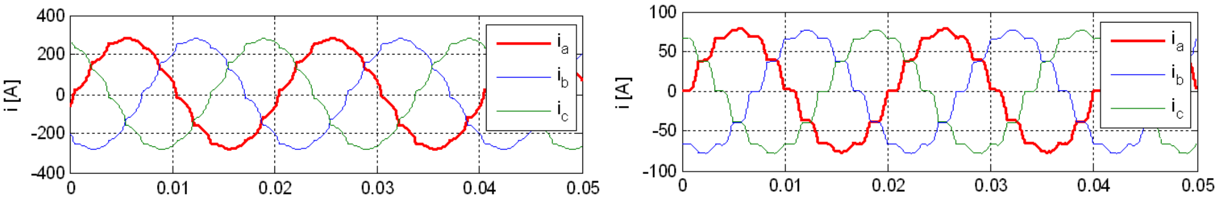


Figure 5. AC current: a) with nominal load, b) AC current with reduced load

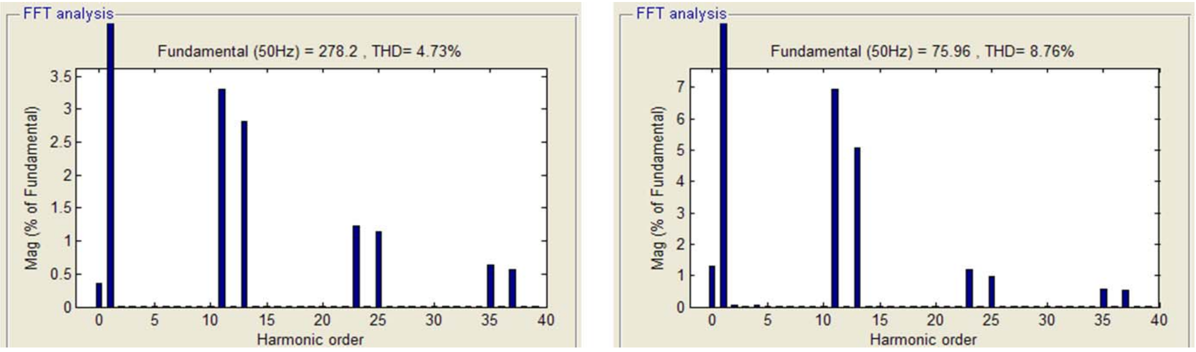
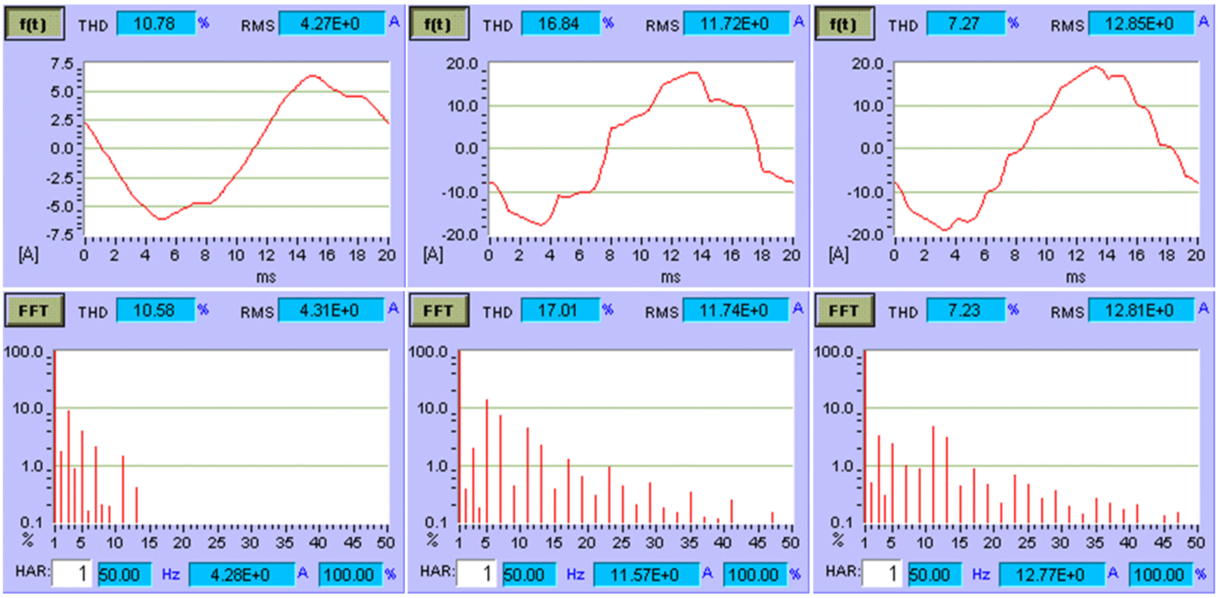


Figure 6. Results of input currents: a) full output power, b) reduced output power



7a) Idle running

7b) 6-pulse rectifier

7c) 12-pulse rectifier

Figure 7. Input AC current (time waveforms and harmonic analysis) for a) idle running (only magnetizing currents of transformer with deformation by magnetizing curve characteristic), b) only 6-pulse rectifier (i.e. according to Fig. 1), c) 12-pulse rectifier according to Fig. 4)

V. MEASUREMENT

The next part of the article presents the measurement results for both simulated cases. There were available two 3-phase regulating transformers For measurements, each with a rated power of 30 kVA. These transformers have magnetizing currents, whose distortion is evident from idle running - see Figure 7a. Harmonic analysis of this current provides value of high order current harmonics. Because of the load (in laboratory conditions, it was possible to perform the load does not exceed 25 A on the DC side), the magnetizing current has some influence in the results of harmonic analysis during the measurement with converter under load (FFT analysis of the magnetizing current of the primary winding is shown in Figure 7b and 7c).

Figure 8. Measurement of input currents (see Fig.7)

Note about presented results:

Figures of measured waveforms and results of harmonic analysis shown in Fig.7 are not fully synchronized with regard to the used method of chosen analyzer. Harmonic analysis is a small delay, which is reflected in a slight deviation of RMS and THD_I values at corresponding waveforms and harmonic analysis.

A. *Non-Controlled 6 –pulse Rectifier*

Figure 7b shows the measured waveform of the AC current for the six pulse connection. These time waveforms and harmonic analysis results in Figure 7b confirm number of pulses of this rectifier. Harmonics that do not correspond to equation (1) are called non-characteristic harmonics. Here are caused by obvious unbalance (for example, a significant asymmetry B phase of the second transformer). Another reason for the presence of harmonics of order 3 and multiples there of already described the influence of magnetizing curve characteristic (such as third harmonic of current is 0.42 A in idle running). This value cannot summarize and compare the results to consider. Similarly situation is in other multiples of third harmonics.

B. *Non-Controlled 12 –pulse Rectifier*

Figure 7c shows the waveform of current. These waveforms is a clear influence of number pulses p=12. This is also confirmed by the results of harmonic analysis in Figure 7c. Absolute and also relative current values are for 12-pulse connections much smaller.

In both cases also generalized harmonic distortion THD_I reflect the expected results.

VI. RESULTS

Using of “classical old” thyristor converters for regulation of output voltage (in AC-side and non-controlled rectifier or controlled rectifier) brings the problems of harmonics spectrum and of lagging power factor (reactive power) in regime of reducing of the output power. The solution of this problem is compensation of power factor or combination of some variants of converter.

Using of special Yy0d11-transformer and 12-pulse rectifier (with the serial or parallel combination of two 6-pulse rectifier) brings many benefits (reducing these unwanted harmonics, size of filtration inductance and ripple of output current).

The using of step-down buck converter and 12-pulse rectifier bring good results in a wide range of working regimes (with minimal values of harmonics, size of filtration inductance and ripple of output current).

Modern semiconductors (i.e. namely IGBT-transistors) still have moreover advantages (the most simply control algorithms, simply control circuits nowadays relatively low cost too).

It was be calculated several combination of values of passive elements (input AC-inductance, input DC-inductance, output DC-inductance, capacitance, additional passive filters etc.) and for other parameters (serial or parallel combination of two 6-pulse rectifiers, switching frequency of step-down buck converter etc.).

The measurement results are affected by the value of the magnetizing current, which is much distorted. Given the potential load of laboratory equipment to the value of max. 9 kVA (total apparent power consumption of the primary side of the network) confirm the results of measuring compliance with simulations. Particularly for the connection of the 12- pulse is a significant reduction of distortion of the current drawn. This is also confirmed by the results. THD_I by concentration at 12-pulse can be considered very low.

VII. CONCLUSION

This paper presents some variants of high power DC source realization with minimized negative influence to supply network.

The comparison of proposed variants (simulation results and measurements) brings as the best variant the 12-pulse non-controlled rectifier with step-down buck converter”

In this paper was not reflected more expensive variants of converter (for example the active rectifier, topology with middle frequency transformers, topology used the energy storage systems etc.)

The paper shows the possibility of using the existing equipment (two-winding transformers and combination of uncontrolled rectifiers etc.) for connecting new high-power device into an existing network without the risk of other negative influences of new devices to the network.

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