HARMONICS ANALYSIS OF OUTPUT VOLTAGE AND CURRENT FOR A THREE-PHASE BRIDGE RECTIFIER-RESISTIVE LOAD (EXTENDED VERSION)

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Abstract: Power rectifiersare important devices for AC to DC conversion. Many systems are supplied through this electronic powerdevice. These systems include DC electric motors, exciter systems of synchronous machines, secondary circuits in power systems and so on.This paper focuses on monitoring and diagnosis of three-phase bridge rectifier faults. The monitoring and diagnosis is desirable in order to ensure energy quality and improved operational efficiency of rectifiers as the main power supply. This paper presents detection nd simulation of faults in a rectifier in order to diagnose failure of elements. The output voltage and current of the rectifier was compared with simulation signals in order to obtain the difference of these signals. Differences between the simulation of faults and rectifier functioning without faults are observed. Also, the harmonics spectra of output voltage and current of three phase bridge rectifier are analysed in order to achieve information for the detection of faults. We observe current and output voltage differences between "healthy" rectifier and rectifier missingone, two or three diodes in resistive load case. The signals of output voltage and current are analysed by FFT method to diagnose rectifier faults.

I. INTRODUCTION

Power rectifiers have been generally used in different areas of engineering, such as: secondary circuit supply in electrical power stations, many types of motor drives, electric vehicles, traction equipments and industrial robotics, etc. The steady state of electronic power components is one of the most important aspectsdetermining the reliability of the electronic power converters. The power rectifier is susceptible to critical damages given by device ageing, overloading and insulation damage, etc. According to previous studies, it has been reported that up to 40% of the faults of electronic power systems are due to breakdown of electronic power components.Thus the monitoring and fault diagnosis of rectifiers is very important in order to decrease the occurrence of system breakdowns and improve system reliability [1].

The diagnosis of open-circuit faults is the most important subject that will be taken into consideration for reliable operation of the power rectifier. In a three-phase bridge rectifier malfunction can be caused by failure of the diodes [2],[3].

The methods most frequently used for detecting faults of rectifying elements are spectral analysis method using Fast Fourier Transform (FFT), output voltage and current detection method, fault diagnose based on neural networks and so on [4],[5].

Based on the above premises, the structure of the paper is as follows: Section II briefly introduces the theory of three phase rectifier faults that is relevant to this study. Simulation models of three-phase rectifier are presented in Section III. Section IV presents the experimental results. Faults are diagnosedby voltage and current waveform analysis. Section V introduces other methodsfor monitoring of rectifier faults by analysis of output voltage and current spectra.

For all methods used for diagnosis we should have the information about of the "healthy" rectifier parameters. In order to take a decision about the state of the rectifier, it is

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necessary to compare the information regarding the rectifier analysed with the "healthy' one. The concluding remarks are summarized in last part of the paper.

II. THREE PHASE RECTIFIER FAULTS

The important faults of three phase rectifier can be classified as following:

- Decreased output voltage value compared with rated;
- Decreased output current value compared with rated;
- Output voltage signal is alternative rather than linear.

Based on the fact thefailure of diodes represents an important percentage of total rectifier breakdowns, our research we'll be focused on this matter.

Causes that lead to diode failures are several:

- Thermal overload or high losses in on-off commutation processes;
- The reverse voltage exceeds the some value;
- Insulation damage. [8]

III. STUDY OF RECTIFIER DIAGNOSIS SIMULATION RESULTS- RESISTIVE LOAD

The rectifiers are constructed as a three-phase rectifier bridge, containing diodes D1 to D6. [8]

Components of rectifier:

- Diode 1N4007 (1A);
- Load R1=500 Ω
- Voltage supply U=30V

The waveforms of voltages and currents have the following colors:

Input voltage- phase 1 U1(green); Current phase 1 I1;

Input voltage- phase2U2 (red); Current phase 2 I2;

Input voltage- phase3U3(blue); Current phase 3 I3;

Output voltage U_{OUT};(orange) Output current (load) I_{OUT}.(pink).

Because of the extensive applications of diodes in the area of electronic power, the breakdown of diodes is considered to simulate open-circuit faults in the three-phase bridge rectifiers [2]. Faults of the diodes could be classifiedin the following three types:

- Fault 1: One of the diodes is broken, i.e. D1 broken[2].
- Fault 2: Two of the diodes of the same bridgeare broken, i.e. D1 broken and D2 broken.
- Fault 3: Three diodes of different bridgesare broken, e.g. D1, D2 broken, and D3 broken, etc.[10],[11],[12]

The simulations of rectifiers are realized in OrCAD [6].

Figure 1 presents an electrical circuit for a "healthy" three-phase rectifier with resistive load. Figure 2 presents waveforms of the input and output voltages and currents.

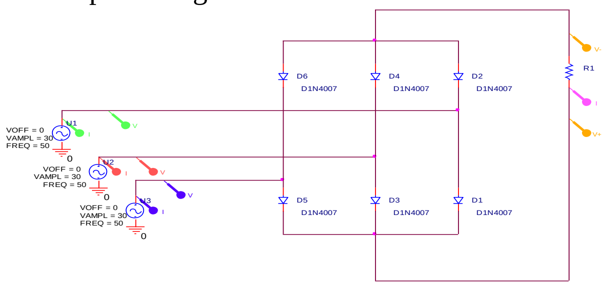


Fig.1 Three-phase rectifier bridge without fault

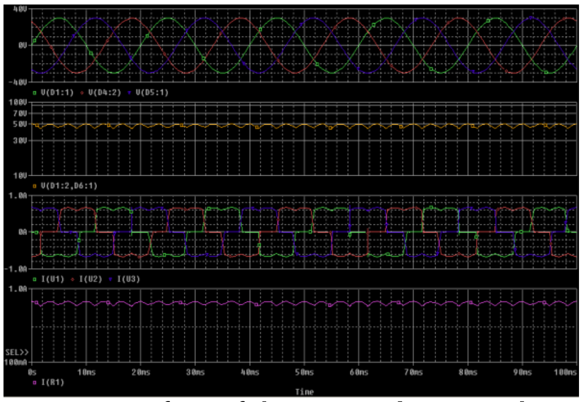


Fig. 2 Waveform of the input and output voltages and currents –no fault rectifier with resistive load

In figures 3 and 4 are presentedthe results of simulation of rectifier without a diode, D1.

We observe that in case the diode D1 does not work input current corresponding to phase 1 is affected. Consequently, the positive alternate of the input current is null. It is observed that the rectified current and voltage are discontinuous when one diode breaks down.

Figures 5 and 6 present the simulation of a power rectifier with resistive load, without D1 and D2 diodes.

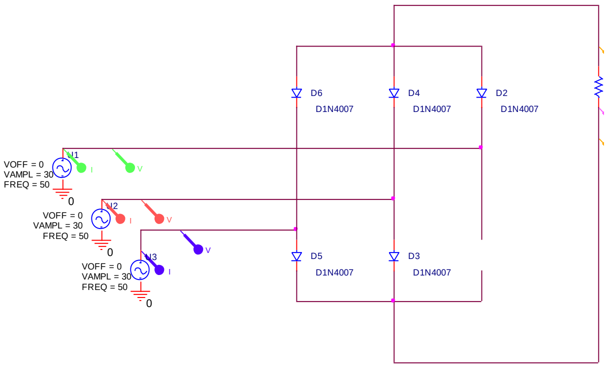


Fig. 3 Three-phase rectifier rectifier without diode D1

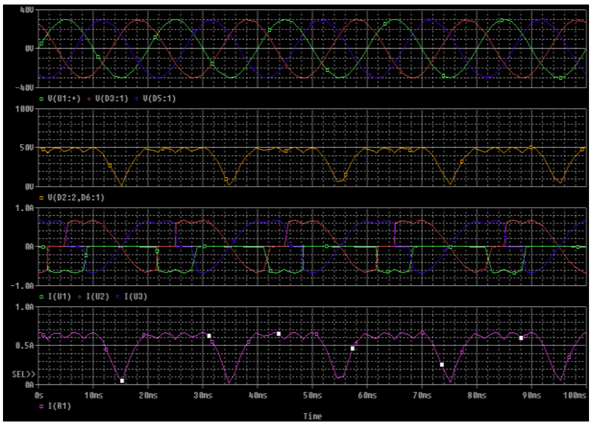


Fig. 4 Waveform of the input and output voltages and current without D1

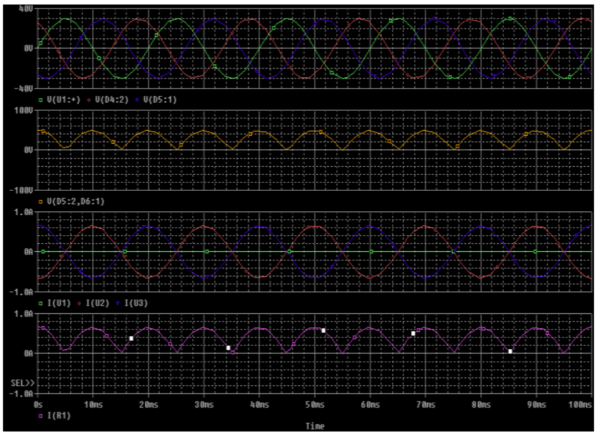


Fig. 5 Three-phase rectifier without D1 and D2

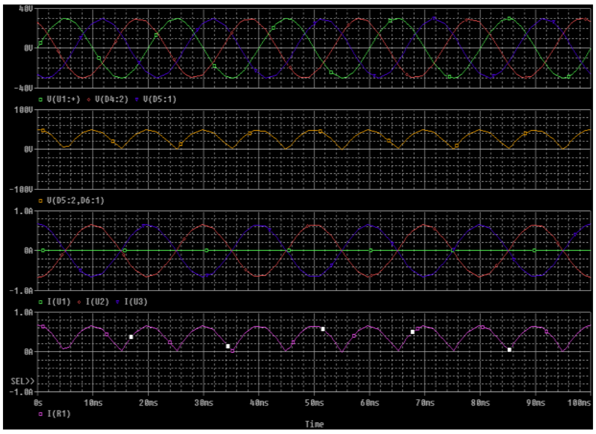


Fig. 6 Waveform of the input and output voltages and current without two diodes D1 and D2

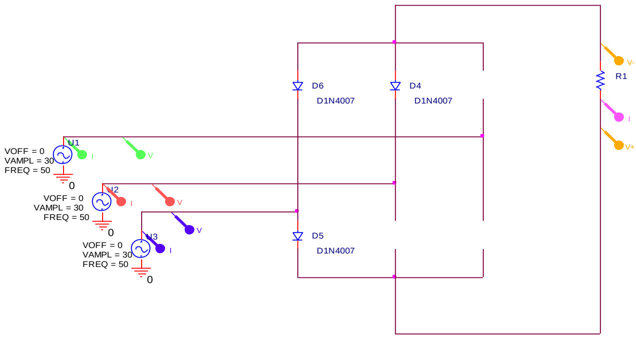


Fig.7 Three-phase rectifier without three diodes D1,D2 and D3

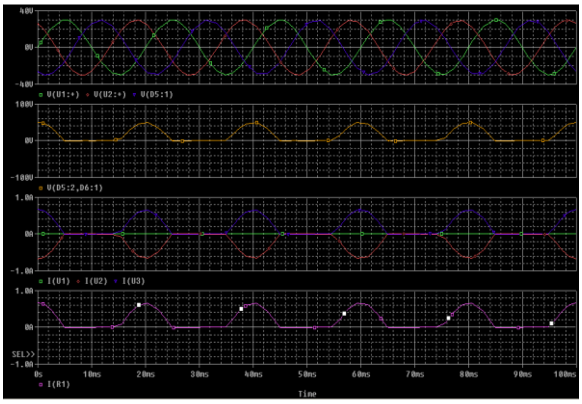


Fig. 8 Waveform of the input and output voltages and current without three diodes D1,D2 and D3

In this case, diodes D1 and D2 are missing and the rectifier works under these conditions similar to being without a phase.

Figures 7 and 8 present the simulation of power rectifier with resistive load, with diodes D1, D2 and D3 broken.

When the diodes D1, D2 of the phase U1 and D3of the phase U2 are simultaneously broken, it looks like phase U1 disasppears and only the diode D4 conducts onphase U2. Currents oscillate coresponding to phase U2 on the negative alternance and phase U3 on the positive alternance. The current and the rectified voltage oscillate only in the time interval when conducting diodes corespond to the phase U3 and the diode D4 of the phase U2.

IV. EXPERIMENTAL RESULTS-RESISTIVE LOAD

The rectifier tested in this paper is a three phase bridge rectifier. This rectifier was built with six diodes type 1N4007/ 1A, supplied by a 230/35V transformer. [8]

In the first step, measurements were realised by using "healthy" three-phase rectifier.

In the second step, same measurements have been done for the same rectifier with provoked faults, like the simulated model.

Data acquisition has been performed with a system connected to a computer.

Output signals and spectra of output voltage and current have been analyzed using data acquisition and Fastview software [7].

Figures 9 and 10 present electrical circuit for "healthy" three-phase rectifier with resistive load and signals of the input and output voltages and currents [8].

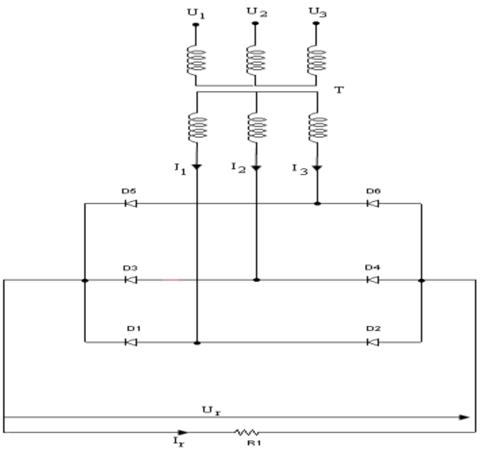


Fig. 9 Three-phase rectifier rectifier without fault

Wiring components are:

- T – power transformer 230/35V;
- Three –phase bridge rectifier with diodes type IN4007 de 1A;
- Load resistance- R1=0÷750Ω.

When the load is resistive, the output voltage waveform and the output current present oscillations bigger than in simulation case.

This deformation occurs becausethe supply voltage of the power transformer is not ideal sinusoidal.

Figures 12 and 13 present the rectifier functioning without D1.

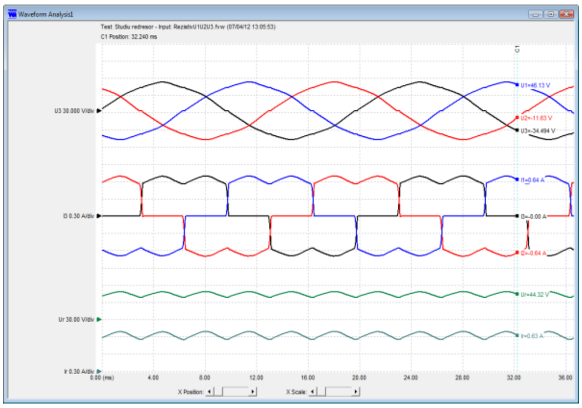
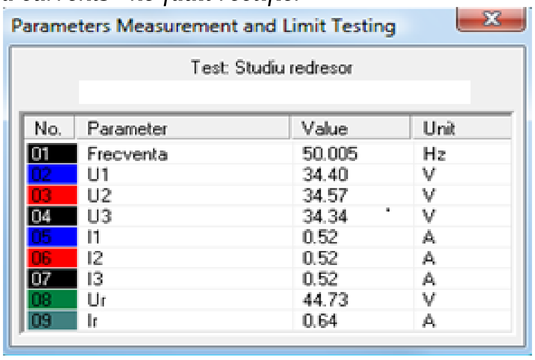


Fig. 10 Waveform of the input and output voltages and currents –no fault rectifier



Parameters Measurement and Limit Testing

Test: Studiu redresor

No.	Parameter	Value	Unit
01	Frecventa	50.005	Hz
02	U1	34.40	V
03	U2	34.57	V
04	U3	34.34	V
05	I1	0.52	A
06	I2	0.52	A
07	I3	0.52	A
08	Ur	44.73	V
09	Ir	0.64	A

Fig. 11 Frequency ,voltages and current values

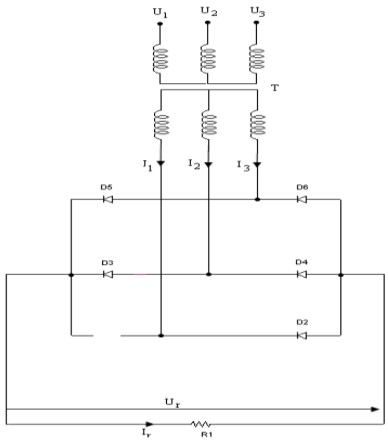


Fig. 12 Three-phase rectifier without one diode

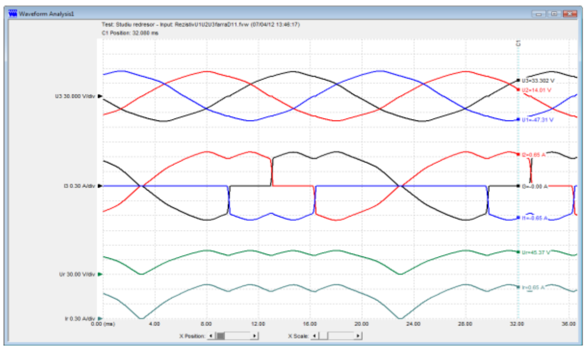
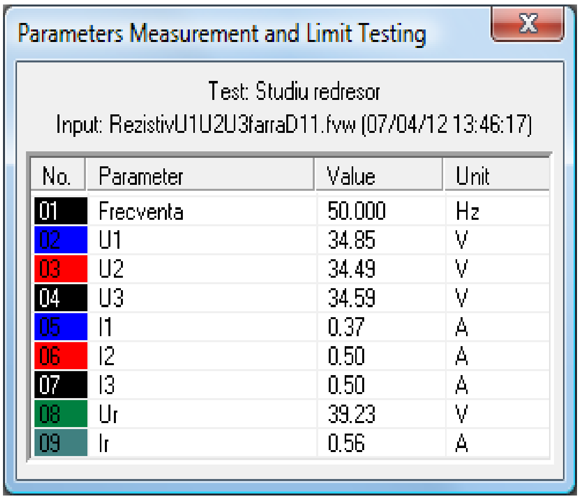


Fig. 13 Waveform of the input and output voltages and current without D1


Parameters Measurement and Limit Testing

Test: Studiu redresor
Input: RezistivU1U2U3farraD11.fvw (07/04/12 13:46:17)

No.	Parameter	Value	Unit
01	Frecventa	50.000	Hz
02	U1	34.85	V
03	U2	34.49	V
04	U3	34.59	V
05	I1	0.37	A
06	I2	0.50	A
07	I3	0.50	A
08	Ur	39.23	V
09	Ir	0.56	A

Fig. 14 Frequency ,voltages and current' valueswithout D1

When diode D1 is damaged, the rectified output parameters decrease at 87.5 % of rated values. The signals of rectified voltage and current are sinusoidal instead almost linear and are zero at 2 π in the when D1 should have been working. Because diode D1 is off, the current of phase 1 (I1) decreased at 74% of the rated value.

Figures 15 and 16 present the rectifier functioning without D1 and D2 diodes.

When the D1 and D2 diodes are broken the U1 phase, disappears. The output voltage drops from 44.73V (all phases are active) to 32.88V. And the output current value drops from 0.64 A, when all phases are active to 0.47A.

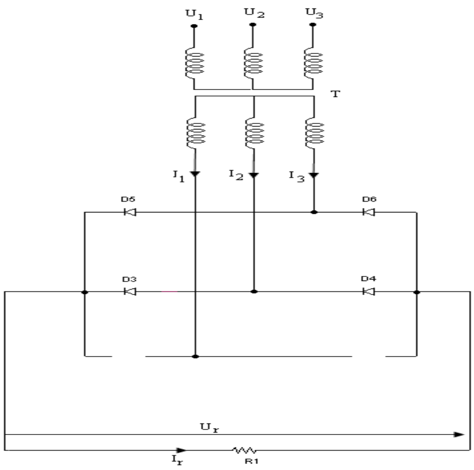


Fig. 15Three-phase rectifier without two diodes

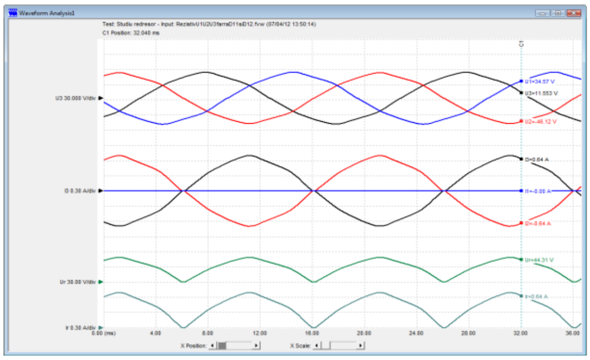
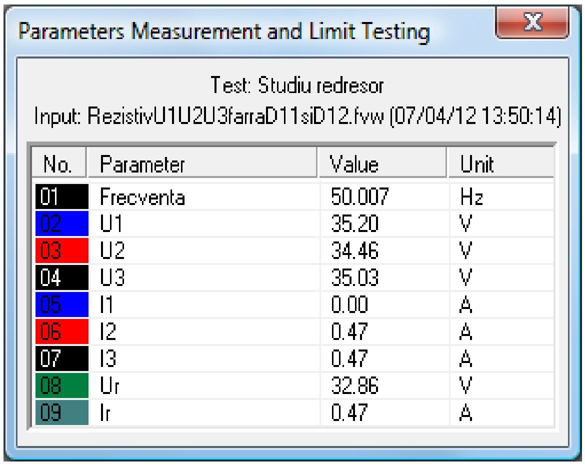


Fig. 16 Waveform of the input and output voltages and current without D1 and D2 diodes


Parameters Measurement and Limit Testing

Test: Studiu redresor
Input: RezistivU1U2U3farraD11siD12.fvw (07/04/12 13:50:14)

No.	Parameter	Value	Unit
01	Frecventa	50.007	Hz
02	U1	35.20	V
03	U2	34.46	V
04	U3	35.03	V
05	I1	0.00	A
06	I2	0.47	A
07	I3	0.47	A
08	Ur	32.86	V
09	Ir	0.47	A

Fig. 17 Frequency ,voltages and current' valueswithout D1 and D2 diodes

In figures 18 and 19 are is presented the rectifier functioning without D1, D2 and D3 diodes.

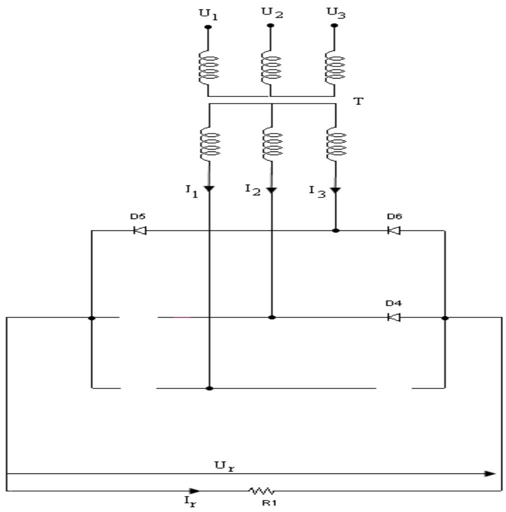


Fig. 18 Three-phase rectifier without three diodes

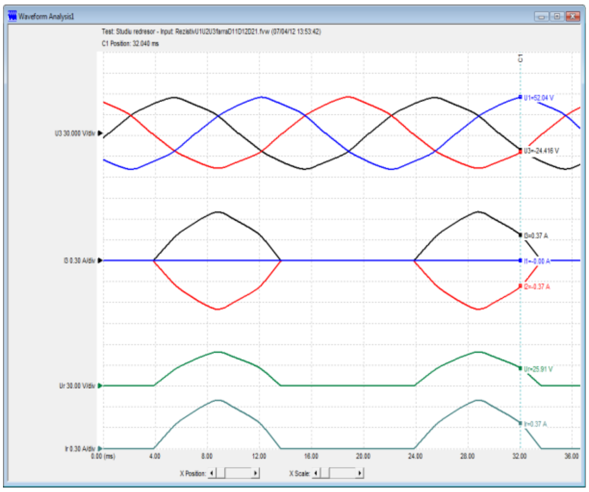


Fig. 19Waveform of the input and output voltages and current without D1, D2 and D3 diodes

Parameters Measurement and Limit Testing

Test: Studiu redresor

Input: RezistivU1U2U3farraD11D12D21.fvw (07/04/12

No.	Parameter	Value	Unit
01	Frecventa	49.981	Hz
02	U1	35.29	V
03	U2	35.01	V
04	U3	35.23	V
05	I1	0.00	A
06	I2	0.34	A
07	I3	0.33	A
08	Ur	23.35	V
09	Ir	0.33	A

Fig. 20 Frequency ,voltages and current' values without D1, D2 and D3 diodes

In case, the diodes D1, D2 and D3 are damaged, the output parameters decrease at 52 % of rated values. Because three diodes are off the current coresponding phase 1 (I1) are zero and phases 2 and 3 decrease by 63%.

V. OUTPUT VOLTAGE AND CURRENT SPECTRA ANALYSIS

In figures 21,22 and 23 we present the harmonic output voltage spectra of "healthy" rectifier and then rectifier with different faults. We analyse the amplitudes of some harmonics and observe an increase of amplitudein rectifiers with faults [12].

In the decision process we need to zoom in the frequency ranges 45-55 Hz and 90-110 Hz. So, we obtain the spectrum presented in figures 19, 20, 22 and 23.

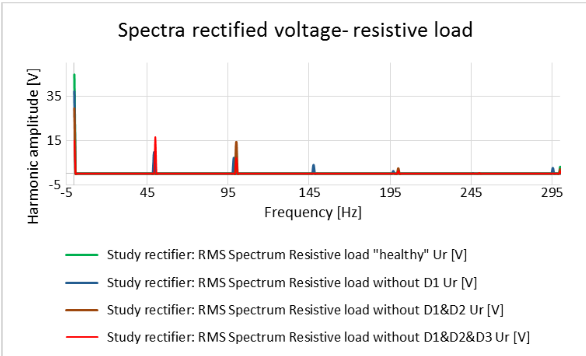


Fig. 21 Comparison of output voltage spectra

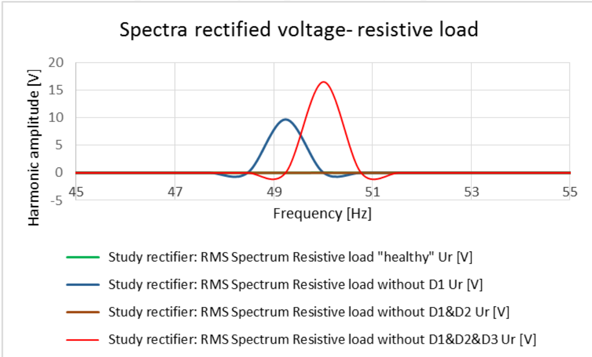


Fig. 22 Comparison of output voltage spectra – 50 Hz frequency zoom

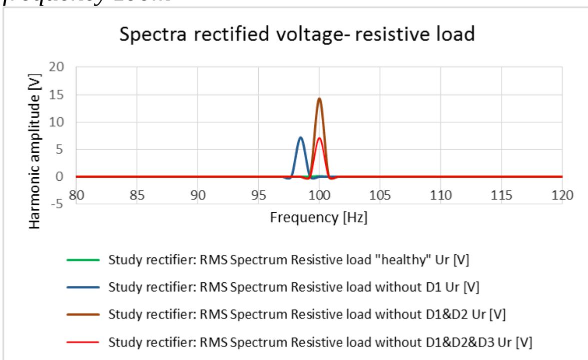


Fig. 23 Comparison of output voltage spectra-100 Hz frequency zoom

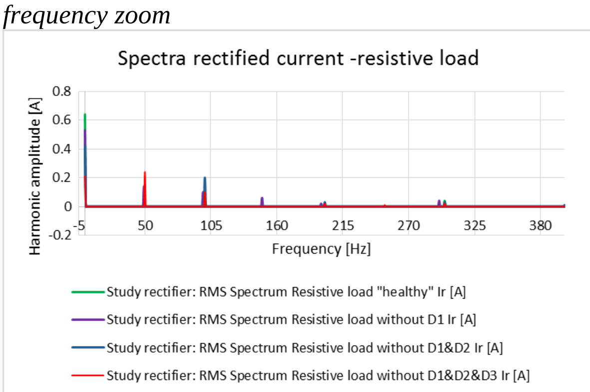


Fig. 24 Comparison of output current spectra-resistive load

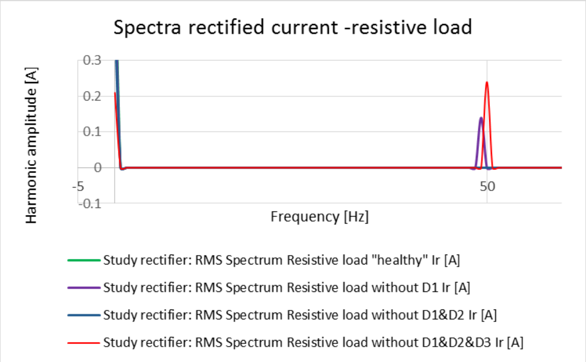


Fig. 25 Comparison of output current spectra-50 Hz frequency zoom

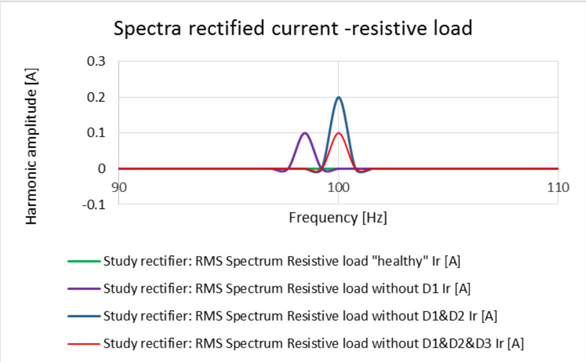


Fig. 26 Comparison of output current spectra-100 Hz frequency zoom

In figures 24, 25 and 26 we present the harmonic output currents spectra for "healthy" rectifier and then for rectifiers with different faults.

Rectifier functionality needs to be controlled at all times. This means that the devices need constant monitoring and quick diagnosis of faults. This can be done by analyzing waveform and output current spectra.

In case of spectral analysis, the amplitude of harmonics has an important value around 50 and 100 Hz.

VI. CONCLUSIONS

The procedures for monitoring and diagnosis of a three phase rectifier based on waveforms of output voltage and current analysis has been exemplified by the simulation and experimental results.

In the case presented, the monitoring of output parameters is very useful to detect rectifier faults such damage of one or more diodes.

Also, based on the spectral analysis of rectified voltage and current we can observe that input and output parameters are different for the "healthy" rectifier and for a similar one with faults.

Using these measurements in the future we intend to design a neuro-fuzzy system based on spectral analysis in order to develop an expert system for power rectifier diagnosis.

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