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Analysis and Study of Currents Harmonic Propagation in Electrical Distribution System

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Rectifiers;

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Power quality;

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Abstract

The increasing use in the industry of non-linear loads based on the power electronic elements introduced serious perturbation problems in the electric power distribution grids. One of the parameters of this system is the waveform which must be as close as possible to a sinusoid. Line currents of three-phase and twelve bridge rectifier suffer from high total harmonic distortion of current (THDi). In this paper we makes an analysis and investigation of harmonics currents propagation in real electric power system with one or tow non-linear loads , the first is a three phase full-wave bridge rectifier (P6) and the seconde is a twelve-pulse bridge (P12) installed in deferent nodes 1 and 2 into an existing distribution network (radial type). In our work we present that this THDi is higher than IEEE standards.

1. Introduction

In recent years, the usage of modern electronic equipment is increasing rapidly. These appliances inject harmonic component to the utility grid, thus contributing to degradation in the power quality [1][2]. The increase in proportion of non-linear load has prompted more stringent recommendations in IEEE Stdandard 519 and stricter limits imposed by utilities [2]. Incidence of harmonic related problems is low, but awareness of harmonic issues can help to increase plant power system reliability [3].

A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency of 50 Hz. Harmonics are the multiple of the fundamental frequency [1][3].

Power electronics devices draw current that is highly non linear in nature and they contain harmonics. Usually high odd harmonics results from a power electronics converter [4].

Fig. 1 shows the typical line current of 6-pulse and 12-pluse rectifier that shows its non linear behavior and richness in harmonic frequencies.

The characteristic harmonics are based on the number of rectifiers (pulse number) used in a circuit and can be determined by the following equation [4][5]:

$h = (n \times p) \pm 1$; Where :

n : an integer (1, 2, 3, 4, 5 …)

p : number of pulses or rectifiers.

This means that a 6-pulse (or 3-phase) rectifier will exhibit harmonics at the 5th, 7th, 11th, 13th, 17th, 19th, 23rd, 25th, etc. multiples of the fundamental. As a rough rule of thumb, the magnitudes of the harmonic currents will be the fundamental current divided by the harmonic number (e.g. the magnitude of the 5th harmonic would be about 1/5th of the fundamental current). A 12-pulse (or 6-phase rectifier) will, in theory, produce harmonic currents at the 11th, 13th, 23rd, 25th, etc. multiples. In reality, a small amount of the 5th, 7th, 17th and 19th harmonics will be present with a 12-pulse system (typically the magnitudes will be on the order of about 10 percent of those for a 6-pulse drive) [4][5].

Fig. 2 shows the typical harmonic spectrum of current of 6-pulse and 12-pluse rectifier. The harmonics generated will be divided into three types that is positive-sequence harmonics, negative-sequence harmonics and zero-sequence harmonics. The positive-sequence harmonics current are the current harmonic components such as 7th, 13th, 19th and negative-sequence harmonics current such as 5th, 11th, 17th that is excessive in phase line which increase the total harmonic distortion of the system[6][7].

While, zero-sequence harmonics current that is triplen harmonics such as 3th, 9th, 15th will flaws through the neutral wire and may cause overheating on that wire [8].

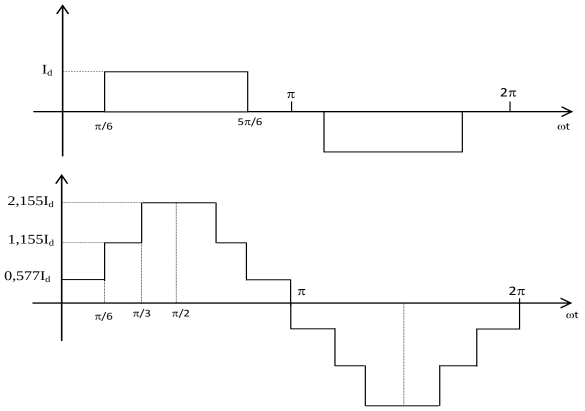


Fig. 1. Input Current Waveform of 6-pulse and 12 pulse Rectifier

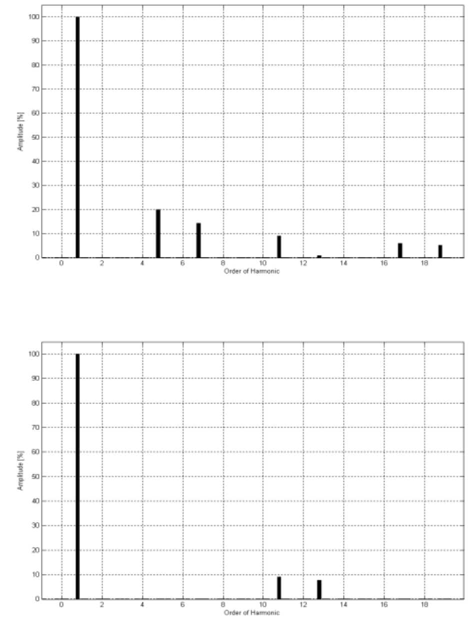


Fig. 2. Harmonic Spectrum Current of 6-pulse and 12-pulse

2. Modeling

Fig. 3 shows the test system (radial distribution network 35 KV). The coupling of the transformer star-triangle is served to eliminate the harmonic of the order 3 [9].

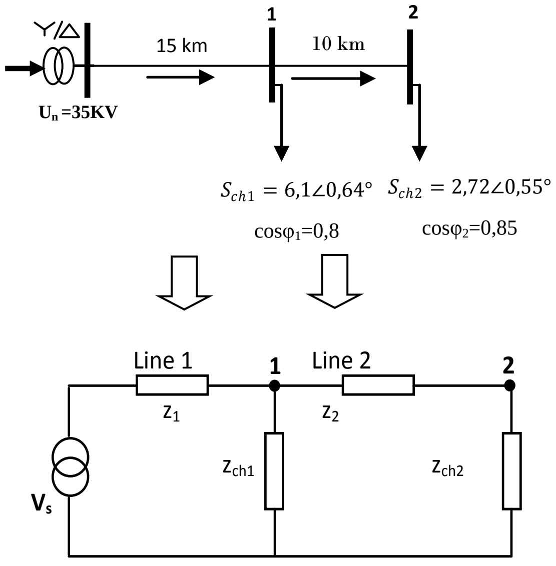


Fig 3. Equivalent single line of distibution Network

2.1. Parameters and loads

The loads are modelled as transversal impedance given in an operated rate: The loads are modelled as transversal impedance given in an operated rate:

$$\begin{aligned} S_{ch1} &= 6{,}1\angle 0{,}6435° = |S_{ch1}|.\cos\varphi_1 + j|S_{ch1}|.\sin\varphi_1 \\ &= P_{ch1} + jQ_{ch1} \\ &= 4{,}88 + j3{,}66 \text{ MVA} \end{aligned}$$

$$\begin{aligned} S_{ch2} &= 2{,}72\angle 0{,}5548° \\ &= |S_{ch2}|.\cos\varphi_2 + j|S_{ch2}|.\sin\varphi_2 \\ &= P_{ch2} + jQ_{ch2} \\ &= 2{,}312 + j1{,}4328 \text{ MVA} \end{aligned}$$

$$Z_{ch1} = \frac{U^2}{\hat{S}_{ch1}} = \frac{35^2}{4{,}88 - j3{,}66} = \mathbf{160 + j120,49}\ \Omega$$

$$\begin{aligned} Z_{ch2} &= \frac{U^2}{\hat{S}_{ch2}} = \frac{35^2}{2{,}312 - j1{,}4329} \\ &= \mathbf{382,82 + j237,24}\ \Omega \end{aligned}$$

Table 1. Parameters of distribution network

Parameters	Values
Vs (KV)	35√2
z_1 (Ω)	2, 3625+j5, 151
z_2 (Ω)	2, 1+j3, 524
z_{ch1} (Ω)	160+j120,49
z_{ch2} (Ω)	382,82+j237,24

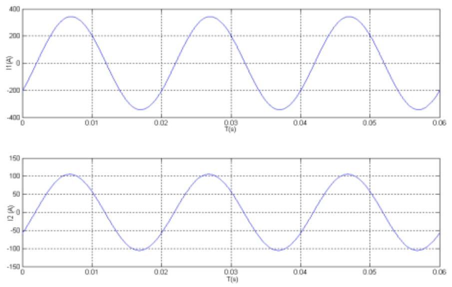


Fig 4 Fondamentales Currents in line 1 &2

2.2. Harmonics Consideration

For our study we decided to investigate six cases, each case depends on two things :

The first is The nature of the pollution load (non linear load), for example a three phase rectifier (6 pulse) and or twelve rectifiers (12 pulse); which injects harmonic currents, and we chose for our study the first four harmonic amplitudes that have the greatest, and are the closest to the fundamental for 6 pulse we tack 5th, 7th, 11th and 13th, and for 12th pulse we take 11th and 13th. The second is the location of the non-linear load (at node 1 or 2).

- Case 1: One non-linear load (P6) at node 1
- Case 2: One non-linear load (P6) at node 2
- Case 3: One non-linear load (P12) at node 1
- Case 4: One non-linear load (P12) at node 2
- Case 5: Two non-linear loads (P6) at node 1, and (P12) at nod 2
- Case 6: Two non-linear loads (P12) at node 1, and (P6) at nod 2

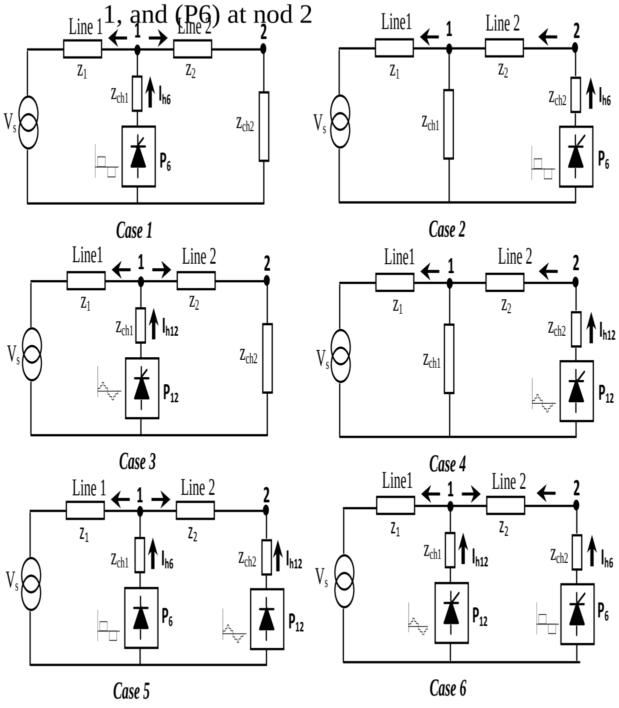


Fig.5 Single diagram of deferent cases studies

Where:

I_{h6} : harmonic current generated by a 6-pulse rectifier

I_{h12} : harmonic current generated by a 12-pulse rectifier

I_{h1}: harmonic current in the line 1.

I_{h2}: harmonic current in the line 2.

3. Simulations results

We use the Matlab Simulink environment for simulation. In each case, we simulate the steady state and draw every time the waveforms of the currents flowing in lines 1 and 2 (I_{h1} and I_{h2}), as well as the harmonic spectrum. For each case study we calculate the total harmonic current distortion (THDi) and the percentage of characteristic harmonics (5th , 7th, 11th and 13th)

⇒ ***Case 1***

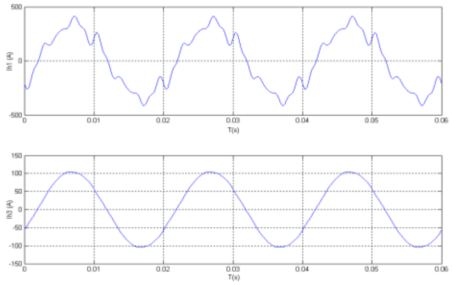


Fig.6. Waveforms of currents lines

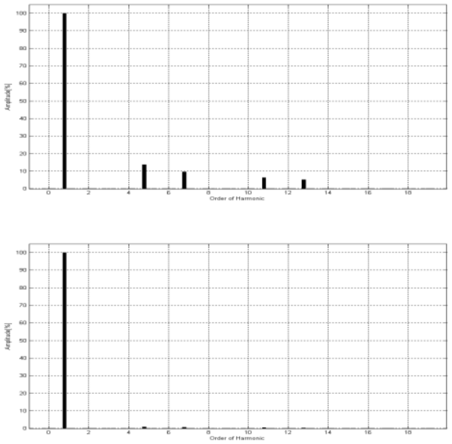


Fig.7 Harmonic Spectrum of I_{h1}& I_{h2}

⇒ ***Case 2***

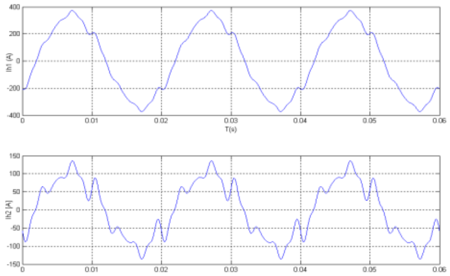
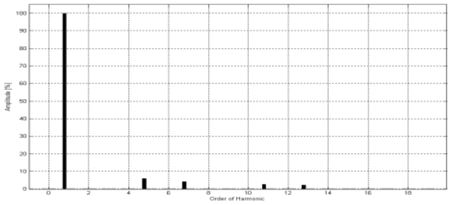


Fig.8. Waveforms of currents lines



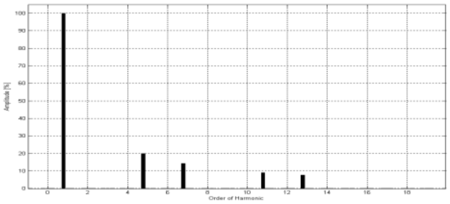


Fig.9. Harmonic Spectrum of I_{h1}& I_{h2}

⇒ ***Case 3***

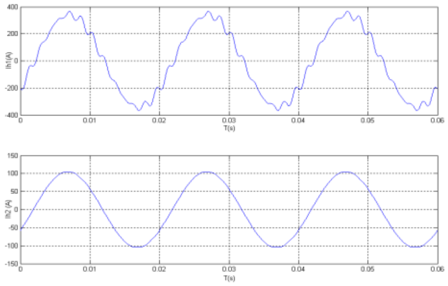


Fig.10. Waveforms of currents lines

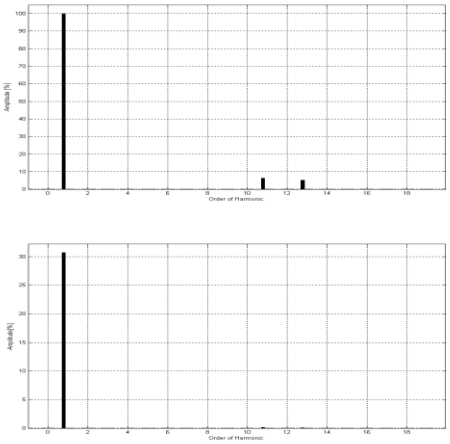


Fig.11. Harmonic Spectrum of I_{h1}& I_{h2}

⇒ ***Case 4***

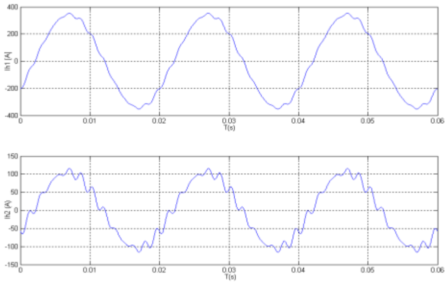


Fig.12. Waveforms of currents lines

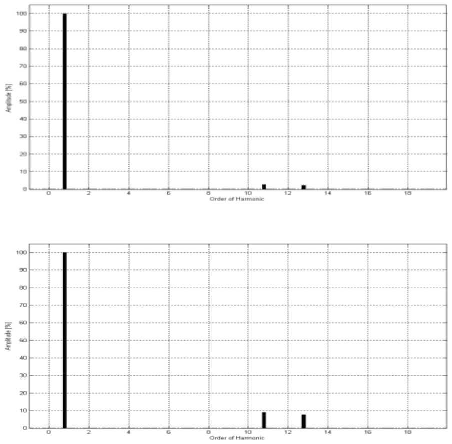


Fig.13. Harmonic Spectrum of I_{h1}& I_{h2}

⇒ ***Case 5***

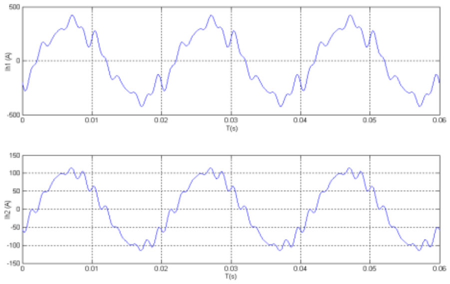


Fig.14. Waveforms of currents lines

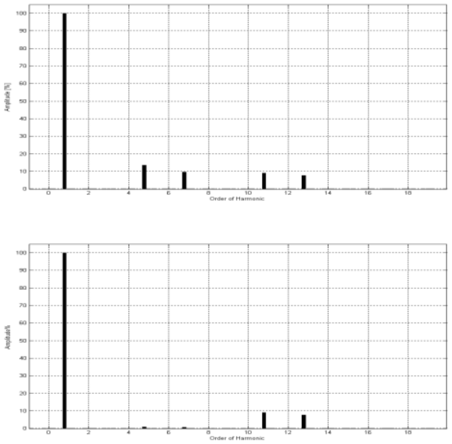


Fig.15. Harmonic Spectrum of I_{h1}& I_{h2}

⇒ ***Case 6***

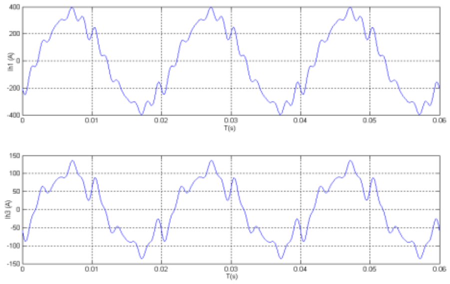


Fig.16. Waveforms of currents lines

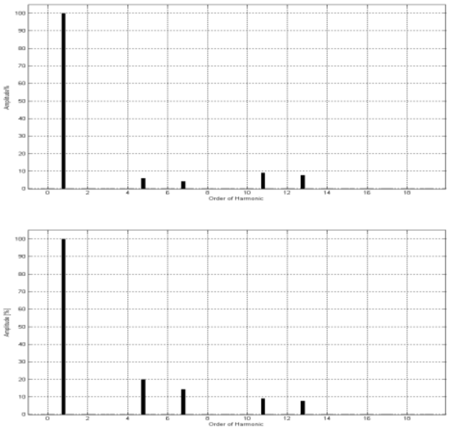


Fig.17. Harmonic Spectrum of I_{h1}& I_{h2}

Table 2. Simulations Results of deferent cases

	I_{h1} [Line 1]		I_{h2} [Line 1]	
CASES	**Magnitude [A]**	**Angle [°]**	**Magnitude [A]**	**Angle [°]**
1	203,76	26,53	57,19	142,69
2	203,85	18,86	57,58	120,95
3	204,05	8,32	57,51	124,81
4	205,35	9,21	57,59	120,65
5	203,77	22,32	57,27	138,46
6	203,93	16,34	57,58	120,97

4. Discussion

We note from the simulation results shown in the table 2:

- For cases 5 and 6 the value of total harmonic distortion of the current (THDi) exceeds the standard used **(IEEE-512- 1992)** in the two lines 1& 2, and it returns to the locations of two non-linear loads both P6 and P12 levels of nodes 1 & 2 of our studied electrical networks.

- In cases 1 and 3 the value of THDi in line 1 exceeds the norm since the polluting load used (P6) in cases 1 and (P12) in case 3 are installed at the node 1 , that connected line 1 and the source, by against the value of THDi in line 2 remains below equal to 1, 26% and 0,56% for cases 1 and 3 respectively.
- In case 4 we note that the THDi = 11,91% in line 2 exceeds the norm since the non linear load (P12) installed at line 2, but in the line 1 we have THDi = 3,51% remaining standards.
- According to the simulation results shown in table 3 we find that there is not much difference aside amplitude among the harmonic current and fundamental current that flows in the same line both 1 and 2 for all cases treated. By cons we have a change of phase shift (phase angle) and it shows the vector sum of harmonics currents but not a scalar sum (proliferation of harmonic currents).

Table 3. Harmonic Currents Calculation

	THDi [%]	h_5[%]	h_7[%]	h_{11}[%]	h_{13}[%]
CASE 1					
Line 1	**18,67**	13,72	9,71	6,28	5,14
Line 2	**1,26**	0,91	0,66	0,43	0,36
CASE 2					
Line 1	**8,05**	5,9	4,21	2,68	2,26
Line 2	**27,31**	20,00	14,29	9,09	7,69
CASE 3					
Line 1	**8,12**	0,00	0,00	6,28	5,14
Line 2	**0,56**	0,00	0,00	0,43	0,36
CASE 4					
Line 1	**3,51**	0,00	0,00	2,68	9,09
Line 2	**11,91**	0,00	0,00	2,26	7,69
CASE 5					
Line 1	**20,53**	13,61	9,71	9,10	7,70
Line 2	**11,96**	0,91	0,66	9,09	7,69
CASE 6					
Line 1	**13,95**	5,90	4,21	9,10	7,70
Line 2	**27,31**	20	14,29	9,09	7,69
IEEE-512-1992	**5**	**4**	**4**	**4**	**2**

5. Conclusion

The research presented in this article concerns the sources of distortion (non-linear loads) and the interaction between those and the propagation of the distortion in the power system.

To achieve this goal we used a portion of the real electric distribution network (radial distribution system in Algeria). In this article, we demonstrated the proportional relationship between the number, nature and location of the non-linear load with harmonic distortion, if the burden of pollution is high and close to the source, it causes more distortion (see table 2); and we have shown that the amount of harmonic currents is in vector form and is not scalar (see table 3).

At the end of this work, we propose to attenuate these harmonics, knowing that it exixte different techniques of filtering harmonics (passive, active and hybrid filtering).

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