Harmonic pollution filtering: case study of a university campus

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Abstract. This paper provides a study of the benefits and improvements in electrical power quality obtained by filtering harmonic pollution. A continuous 7-day measurement by a network analyzer at the secondary level of a higher education institution's transformer proved the existence of important harmonic pollution. We proposed to attenuate these harmonics by installing passive filters at the general circuit breaker. The simulations were carried out with Matlab/Simulink software, based on a set of data measured by the network analyzer. This harmonic pollution-filtering project will improve the quality of power and make significant energy savings.

1. Introduction

The nonlinear loads in the modern electrical distribution systems inject a massive quantity of harmonic currents. This distortion of currents affects mainly the power waveform and thus disorder the loads related to this power system components [1]. The harmonic distortion is a frequently and easily occur in electrical power networks. This is generally resulting from the nonlinearity of domestic and commercial loads such as fluorescent lamps, TV, power converters, etc. It results also from the speed variation of motor drives used generally to connect those domestic loads with industrial pumps, and compressors. When the total loads of the system operate simultaneously, the cumulative impact causes massive harmonic distortion levels, extra losses, and minimizes the power factor [2]-[3]. Harmonic power creates several problems such as harmonic losses, harmonic resonances, and interference with other electronic equipment [4]-[5]. Therefore, regarding these important concerns, there is an essential need for the elimination of substantially growing harmonic impacts in electrical distribution system. Passive filters considered as an alternative to minimize the harmonic effects from electrical power systems. Those filters present several advantages namely being unexpensive in comparison to other different harmonic elimination techniques. Moreover, they increase the power factor of the systems by injecting reactive power[6]. The series tuned connection of shunt passive filters reduces the impedance values for appropriate current harmonics, these filters formed at a frequency more important than system frequency. The parallel (shunt) connection is adopted by the industrial power system. Total Harmonic Distortion THD is kept small than permissible limits i.e. 5% for the voltage and 10% for the current. The presence of non-linear loads in electrical systems create currents and voltages distortions, which make undesired effects depending on the type of load and its intercommunication with other components, harmonic distortions are generally observed in failing power distribution systems and in most cases include odd harmonics of third, fifth, seventh, ninth and11th orders. Authors in [7] also discuss a methodology to identify harmonics in power systems using wavelet transform. However, in a practical case, a pretreatment step is required to minimize the high noise levels before applying the proposed harmonics wavelet method. Kordestani et al in [8], present a systematic literature review of recent failure diagnosis systems, including the principal strategies and some of the several important employment areas for failure analysis. A review of faults diagnostic applying signal processing methods in induction motors are discussed in [9]. The paper shows also that the receipt and processing of signatures can be used to characterize the nature of faults in electrical machines. Alternatives for the fault diagnosis in electric motors are presented in [10]. The presence of harmonics in fault situations is also introduced in these works. A comparison of technical and economic advantages between these technologies has been done in [11]. Several studies have been published recently which deal with harmonic pollution in buildings. Jingkai Wu et al [12] performed simulations on Matlab to analyze the characteristics of the harmonics of a PV system. A. Elkholy [13] proposed mathematical models to characterize the current total harmonic distortion and the power factor at two different operating modes. Jalil Yaghoobi et al [14] studied the impact of high-frequency harmonics (0-9 kHz) generated by grid-connected inverters on distribution transformers. The authors claimed that a loss due to higher frequency harmonics causes a 22% acceleration of aging for transformers. Wallace [15] presented harmonic attenuation strategies in variable frequency drive applications. Boharb et al [16] studied the harmonic pollution generated by two variable speed drives with a power of 250 kW each in a Moroccan industry. The authors proposed the attenuation of this harmonic pollution by passive filters and they estimated an energy saving of 2.24% compared to the consumption of the two engines. There is a very large example of studies that deal with harmonic pollution, but most of them deal with the industrial sector because it is the most polluting of the electrical network due to the massive use of non-linear loads. Studies that deal with harmonic

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pollution in buildings or domestic installations are very rare. In this article, we will study the case of tertiary buildings, which are among the largest consumers of energy. The study building is a faculty of science and technology of Fez based in Morocco.

2. Methodology

2.1. Measurement analyze

The Faculty of Science and Technology of Fez has a 630 kVA power transformer that supplies the main switchboard and the secondary switchboards. A 100 kVAr capacitor bank is installed on the secondary of this transformer to compensate for reactive energy. A three-phase network analyzer was installed for a continuous week at the faculty, exactly at the circuit breaker (fig. 1). Table 1 shows the technical characteristics of the analyzer used. The network analyzer measures all the electrical parameters on the three phases every 20 seconds and simultaneously records the measured values, the following records show the curves obtained by the software and their analyzes.

Table1. Technical characteristics of the network analyzer

Measuring instrument	Technical characteristics
Three-Phase power analyzer recorder	- LCD 320 x 240 - Precision: ±0,5 % - Peak voltage and current. - Voltage phase-phase :up to 600 V. - Current up to 3000 A (according to sensors used). - Frequency from 40 to 70 Hz. - Active, reactive and apparent power per phaseand their aggregate. - Active, reactive, consumed and produced energy. - Harmonics for voltage, current, or power upto the 50th order.

Fig. 1. Three-phase power analyzer recorder installed at the main circuit breaker

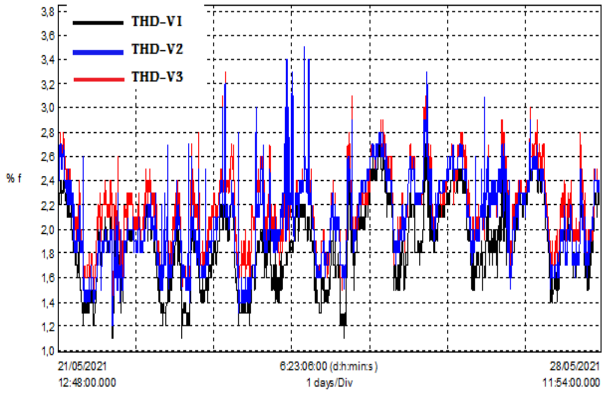

Fig. 2. Measurement of the three THD-V

From the above curves, it is concluded that the overall rate of voltage harmonics is acceptable; it is lower than the tolerated threshold limit of (5%). This harmonic voltage pollution is due to the poor quality of energy supplied and to the harmonic currents created on site.

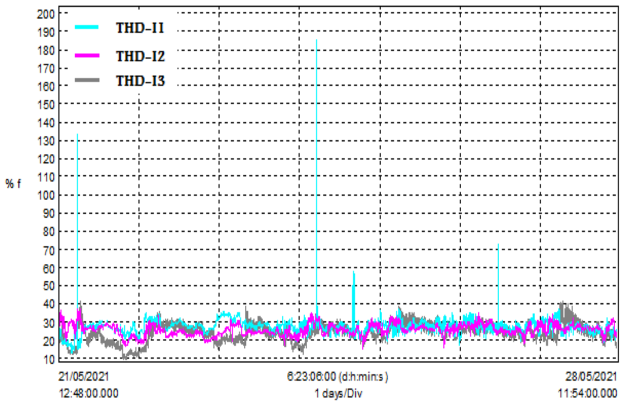

Fig. 3. Measurement of the three THD-I

From the curve Fig. 3, it can be concluded that the overall rate of harmonics of the current has a high level of 25% on average for the three phases (greater than the tolerated threshold of 10%). This harmonic pollution is due to the non-linear loads connected to this transformer: lighting, IT equipment (computers, servers, etc.). The analysis of the anti-harmonic spectra shows that the harmonics 5,7, 11, and 13 are the most important as shown in the example spectrum in fig. 4.

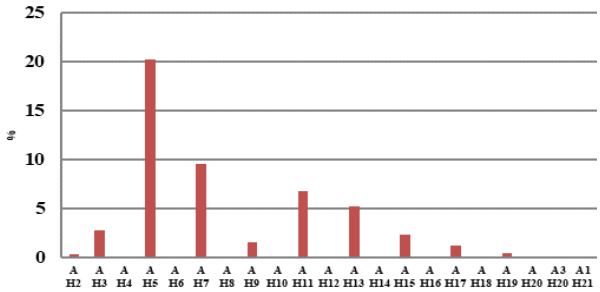

Fig. 4. Current harmonics spectrum

Fig.5. Present a variation of active, reactive and apparent power during a day

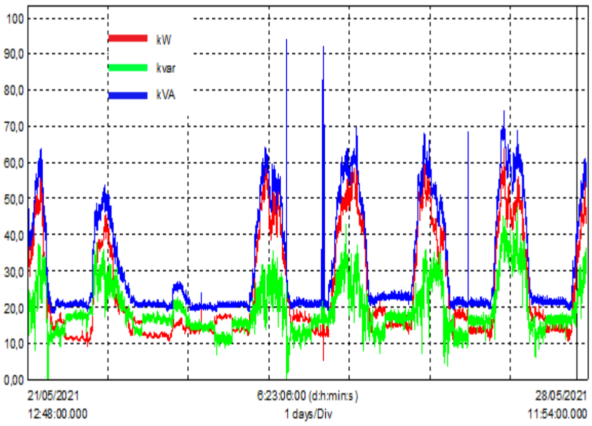

Fig.5. Active, reactive and apparent power measurement

After analyzing the above curve, we can conclude that:
- The total active power (in red) shows variations between 10 kW and 60 kW with an average of 24 kW. Thus, we notice that the power curve is almost periodic during normal working days and it stabilizes around 15 kW during weekends.
- The total reactive power (in green) varies between 10 kVAr and 45 kVAr with an average of 19 kVAr. We can estimate that 20 kVAr is the power of the battery to be installed to have a power factor near to 1.
- The apparent power varies between 20 kVA and 60 kVA with a power peak of 93 kVA (a power peak due to the starting of several loads at the same time).

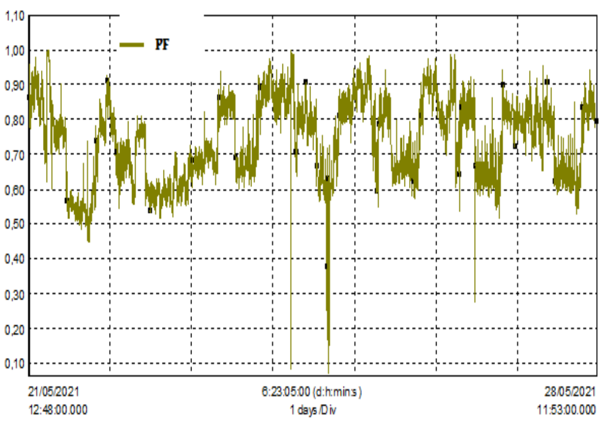

Fig.6.PF measurement

From fig.6 we can see that the measured power factor has an average of 0.74. This value remains fairly low and this is due to the lack of a capacitor bank to be installed and to the harmonic pollution already indicated.

3. Simulations

The treatment of harmonics has become essential for the protection of loads sensitive to harmonics, the reduction of electrical consumption, and the reduction of maintenance costs [6]. The treatment of harmonics can be done by installing passive, active, or hybrid anti-harmonic filters [7]. The treatment of harmonics improves the quality of the power supplied and gives important results [8]. We proposed to attenuate the harmonic distortion measured by passive filters. In order to calculate the reductions that can be obtained by installing anti-harmonic filters, we have carried out simulations by Matlab/Simulink on a load that breaks down from a non-linear part and another linear part whose powers have been chosen according to the measurements obtained by the analyzer. Fig. 7 presents the circuit carried out on Simulink.

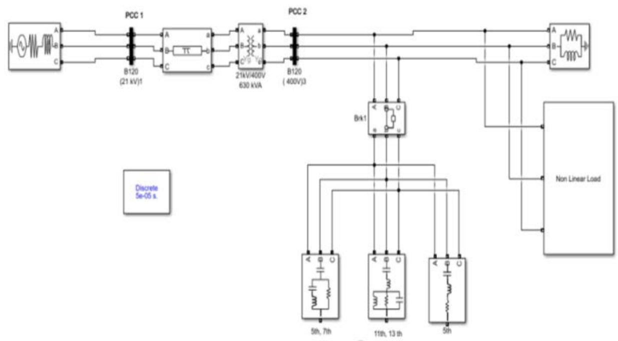

Fig. 7.schema of the electrical circuit in Matlab/Simulink

For the simulations, we take care of the following data:
- The source: THDV = 0%, f = 50 Hz, 21 kV.
- Transformer : Voltages U1 = 400 V, U2 = 21 KV, Ucc = 4%.
- Voltage and curent imbalance = 0%
- Cable length between the source and the establishment's transformer: 6000 meters.

The power absorbed by the faculty has variations (see fig. 4), for this, it has been proposed to do the sizing of the passive filter to be installed about the maximum power demand, which is (50 kW, 30 kVAr).

4. Results and discussion

We proposed to perform the simulation for three load levels: the night mode where the power is almost stable and equal to 15 kW and the day mode where the power varies around 50 kW and the average, which is 30 kW. For each mode, we looked for the two powers of the two linear and non-linear loads to have the same parameters measured by the network analyzer. For the night mode where the power is stable and equal to 15 kW, Table 2 summarizes the simulation results obtained before and after the installation of the anti-harmonic filters.

Table2. Simulation table before and after installation of passive filters at point PCC2 (P = 50kW)

	Without filter	With filter	Reduction
THDV (%)	2.56	1.07	-58.20 %
THDI (%)	22.8	5.343	-76.57 %
Total current (A)	83.62	69.44	-16.96 %
PF (Power factor)	0.872	1	+14.68 %
Apparent power	58.22	48.34	-16.95 %
Reactive power	28	0.1076	-99.62 %
Active power (	50	48.84	-2.32 %

For the case where the power is 50 kW, the comparison between the two states before and after installation of the filters (Tab. 2) allowed us to draw the following conclusions:
- At point PCC2, the passive filters have made it possible to considerably reduce the two harmonic distortion rates (see fig. 8)

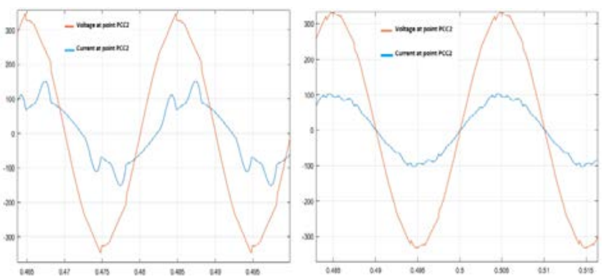

Fig.8. Current and voltage wave before filtering "left one" and after filtering "right one"

- Reduce the reactive power, apparent, and a power saving of 0.32 kW.
- An improvement in the overall power factor of the installation from 0.872 to 1.

In the same way, we proceeded by simulation of all of the following cases: P = 15 kW, P = 30 kW. = And P = 50 kW. Tab 3 summarizes the reductions obtained at points PCC1 and PCC2 of the network.

By analyzing the results of Table 3, we can conclude the following:

- The action relating to the improvement of energy efficiency by filtering harmonics will reduce the active power consumed, which will result in significant direct energy savings. The maximum reduction is observed at PCC 2 when the load consumes 15 kW.
- A decrease of 9.8 kVA in apparent power and this when the load is at its maximum power demand. This will allow us to reduce the power subscribed and to achieve budgetary gains for the faculty
- An improvement in the power factor at the PCC2 point of 0.128 at the high power in the case 3with the reactive power injected by the anti-harmonic filters.
- Compliance with IEEE 519 standards by meeting THDI <10% and THDV <5%.
- Better quality of the supply voltage.
- An increase in the service life of electrical network equipment [12].
- Elimination of additional errors due to harmonics for energy meters.

Table 3. The results after installation of passive filters

		Case 1 P=15 kW	Case 2 P=30 kW	Case 3 P=50 kW
PCC1				
Powers	(kW)	-0.58	-0.57	-0.32
	(kVA)	+12.03	+4.33	-4.45
	(kVAr)	+14.69	+10.63	-14.11
Current (A)		+0,33	+0.119	-0.122
THDI (%)		-27,9	-23.5	-18.28
THDV (%)		-0,01	-0.03	-0.01
PF		-0,306	-0.183	+0.059
PCC2				
Powers	(kW)	-2.74	-2.46	-1,16
	(kVA)	-3.62	-4.45	-9.87
	(kVAr)	-28.73	-28.46	-27,89
Current (A)		-5.2	-6.43	-14.18
THDI (%)		-18.12	-20.4	-17.45
THDV (%)		-0.59	-0.99	-1.49
PF		+0.0023	+0.052	+0.128

5. Conclusion

This article presents the results obtained by a harmonic pollution filtering study in tertiary buildings and we took the example of the category of higher education buildings. The installation of a network analyzer at the general transformer level showed the existence of significant harmonic pollution with a current THD exceeding 20%. For the results to be obtained by installing passive anti-harmonic filters, Simulink/ Matlab carried out simulations on a load that contains a linear part and another non-linear part, the choice of their power of which is identical to the measurements carried out.
The simulations have shown significant advantages when the power varies between a minimum value of 15 kW to a maximum value of 50 kW.

References

1. Gandoman FH, Aleem SHA, Jurado F, Ali ZM, Ahmadi A, Shamkhani K (2020) A methodology for imposing harmonic distortion's penalty in customers bill. Electr. Power Syst. Res 183:106268
2. Memon ZA, Uqaili MA, Soomro MA (2011) Experimental Analysis of Harmonic Mitigation Effects on Three Phase Six Pulse Converter by Using

Shunt Passive Filter. Mehran Univ. res. j. eng. technol 30:653–656

3. Nikum K, Saxena R, Wagh A (2021) Power quality issues in commercial load-impact and mitigation difficulties in present scenario. In: ICCCE 2020. Springer, pp 63–78
4. Aleem SHEA, Zobaa AF, Aziz MMA (2011) Optimal $ C $-type passive filter based on minimization of the voltage harmonic distortion for nonlinear loads. IEEE Trans. Ind. Electron 59:281–289
5. Zubi H, Dunn R, Robinson F (2010) Comparison of different common passive filter topologies for harmonic mitigation. IEEE, pp 1–6
6. Hava AM, Zubi H (2005) Performance comparison of various passive harmonic filters for adjustable speed drives. IEEE, pp 1295–1300
7. Kordestani M, Safavi AA, Saif M (2017) Harmonic fault diagnosis in power quality system using harmonic wavelet. IFAC-PapersOnLine 50:13569–13574
8. Kordestani M, Saif M, Orchard ME, Razavi-Far R, Khorasani K (2019) Failure prognosis and applications—A survey of recent literature. IEEE Trans. Reliab
9. Basak D, Tiwari A, Das S (2006) Fault diagnosis and condition monitoring of electrical machines-A Review. IEEE, pp 3061–3066
10. Li W, Mechefske CK (2004) Induction motor fault detection using vibration and stator current methods. Insight-Non-Destructive Testing and Condition Monitoring 46:473–478
11. De Almeida AT, Ferreira FJ, Quintino A (2012) Technical and economical considerations on super high-efficiency three-phase motors. IEEE, pp 1–13
12. Lin W-M, Hong C-M, Chen C-H (2011) Neural-network-based MPPT control of a stand-alone hybrid power generation system. IEEE Trans. Power Electron 26:3571–3581
13. Elkholy A (2019) Harmonics assessment and mathematical modeling of power quality parameters for low voltage grid connected photovoltaic systems. Sol Energy 183:315–326
14. Yaghoobi J, Alduraibi A, Martin D, Zare F, Eghbal D, Memisevic R (2020) Impact of high-frequency harmonics (0–9 kHz) generated by grid-connected inverters on distribution transformers. Int. J. Electr. Power Energy Syst 122:106177
15. Wallace I (2021) Harmonic Mitigation Strategies in Variable Frequency Drive Applications. ASHRAE Trans 127:452–459
16. Boharb A, Allouhi A, Saidur R, Kousksou T, Jamil A, Mourad Y, Benbassou A (2016) Auditing and analysis of energy consumption of an industrial site in Morocco. Energy 101:332–342