Impact of appliances harmonic content in microgrid environments

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Abstract— **Harmonic contents are a growing and challenging problem. The increasing number of electronic appliances and the use of adjustable speed drivers (ASD) in fridges, dryers and washers as well as the insertion of distributed generation (DG) in smart grids using power electronics converters are some of many generators of harmonic contents presented in distribution systems. This study proposes an approach to identify the harmonic losses generated by appliances in distribution power systems likely to microgrid environments considering DG and susceptible of islanding. To develop this methodology models of appliances using real data measurements associated in different scenarios are created. A typical distribution system multi grounded neutral (MGN) is employed to determine the impact that each appliance harmonic contents have in the distribution power system technical losses.**

Index Terms — Harmonic losses, Distribution power system, Microgrids, Appliances.

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I. INTRODUCTION

This The increasing number of electronic appliances and application of adjustable speed drivers (ASD) in fridges, dryers and washers [1], [2], as well as the insertion of distributed generation (DG) and electrical vehicles (EV) using power electronics converters in the grid [3]-[5], are some of many generators of harmonic contents presented in distribution systems.

The distortion created by these non-linear loads worsen the system power quality, contributing to overheating, premature failure of equipments, operation of protective devices and even resonance conditions that can deteriorate the system operation and cause metering inaccuracies [6]. Also, problems as voltage droop, flicker and interruption can be attributed to harmonic distortion [7].

All of these factors lead to economical losses that can be directly assigned in a case of interruption and equipment failure or added in the power system technical losses, as active and reactive power losses, [8]. This study works in the spotlight of the technical losses generated by appliances harmonic components in the distribution power systems likely to microgrid environments considering DG and susceptible of islanding .

In the literature, several approaches are proposed to study the impact of appliances harmonic contents in the distribution power system. Due to its influence on the system power quality, the studies are usually focused on the distortion placed on the grid. Reference [4] determines THDV,I and IHDV,I factors in the Point of Common Coupling (PCC), addressing the impacts of DG harmonic distortion on a residential distribution system level. Reference [9] emulates a typical North American home and verifies if the IEEE-519-1992 limits are respected. Reference [10] proposes a filter technique to correct power factor and sustains voltage and current values under the distortion standard levels, while [11] describes that this technique is likely to result in harmonic resonance and proposes a technical losses reduction by optimal transformers and feeders loading.

Considering the previously background, this paper presents an approach regarding the distribution system technical losses caused by home appliances harmonic components. The proposed methodology should identify the harmonic losses that each type of appliance implies on the grid. To develop this methodology, models of appliances were created using real data measurements [12]. Further, associations were made in order to generate different load scenarios. A typical distribution system multi grounded neutral (MGN) was employed to determinate the harmonic impact that each type of equipment generates in distribution systems´ technical losses.

II. TECHINICAL LOSSES

Technical losses are usually an estimation generated by approximation methods and assumptions. It is obtained calculating the active power losses at peak load conditions, multiplied by a correction factor and the desired period of time [12]. These losses can be classified by the segment that they occur: transmission and sub-transmission lines, substation power transformers, primary distribution lines, distribution transformers, secondary distribution lines, service drops and others [13]. These segments are represented in *Fig. 1*.

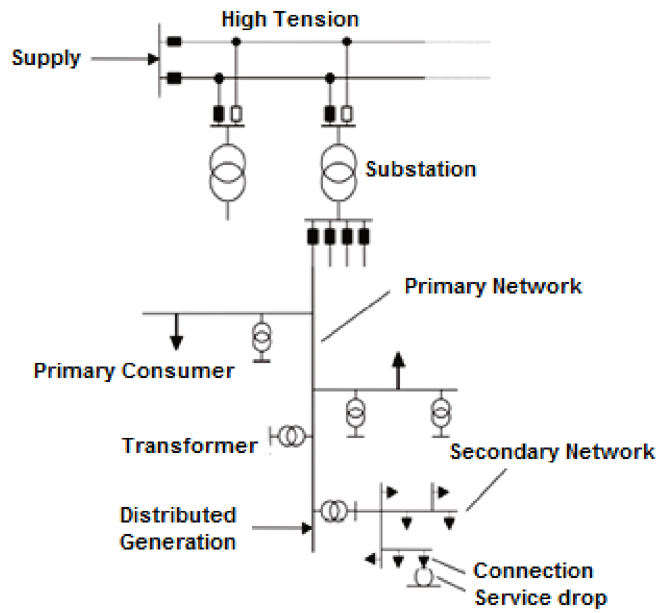

Fig. 1: Distribution System segments [14]

This paper attains to the harmonic impact on technical losses developed at residential distribution system level, which corresponds to distribution transformer and secondary network segments. The proposed system can be fed by the network associated with distributed generation or work in islanded mode being completely powered by DGs.

III. Appliances Harmonic Losses Proposed Methodology

A. Appliances Modeling

The appliances modeling is an extremely important feature in the study of harmonics impact caused by residential loads, because it provides the basis of all further development. In this work, a model composed of current sources connected in parallel with a series impedance representing the load is applied. A similar model is used in [15]. This model is illustrated in *Fig. 2*.

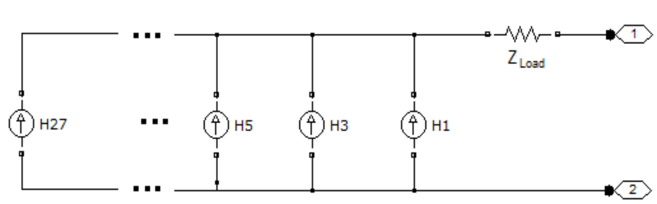

Fig. 2: Load model representation

It may be noted that the load is represented up to its 27th harmonic component yielding a precise representation of the real equipment. The appliances harmonic components data applied are available in [15]. The pieces of information regarding the measurement process and error analysis are depicted in [16].

To show the accuracy of the model, the current wave form from a CLF Lamp model is presented in *Fig. 3*.

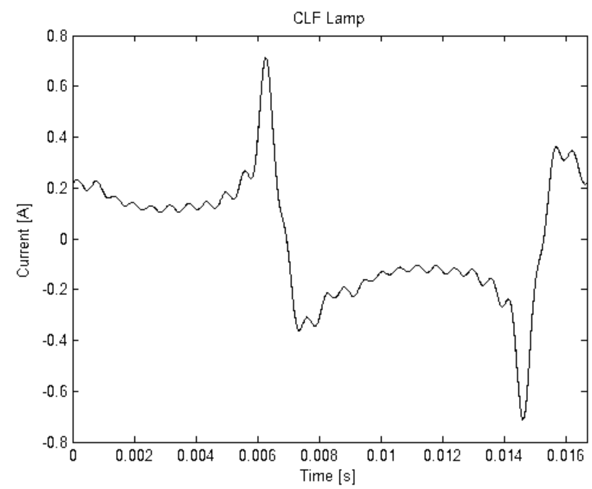

Fig. 3: CLF Lamp model current wave form

B. System Modeling

The system simulation model is a per unit representation of a base case system of Alberta, Calgary [15]. As depicted in the diagram represented in *Fig. 4*, it has three parts: primary system, service transformer and secondary system. At the secondary system, harmonic contents are injected to the grid by houses connected to the service transformer. In order to analyze the harmonic impact, measurements are made in each branch to determine the losses caused by harmonics components in service transformer and secondary system.

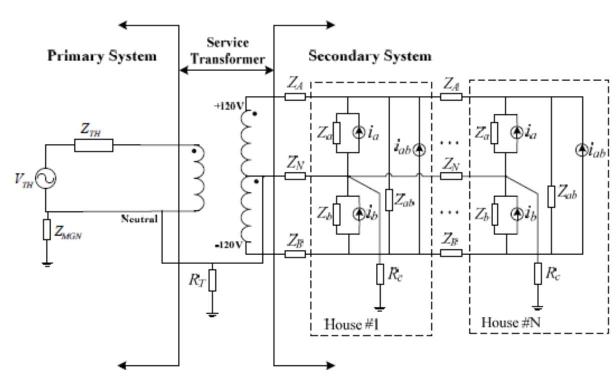

Fig. 4: Simulation system diagram [15]

It is important to note that in this system each service transformer supplies 10 residences.

C. Simulation Process

To simulate the appliances energy consumption, benchmark data from the Comprehensive Energy Use Database of the Office of Energy Efficiency of Natural Resources Canada [17] is applied. This data is expressed in *Table 1 – 2.* It provides information on the electricity use of the average Canadian household based upon surveys and other sources such manufacturers, electricity distribution companies and Statistics Canada.

Using this data, different operating scenarios were simulated in order to achieve the annual housing consumption, and finally the harmonic technical losses generated per each appliance in the distribution transformer and secondary system level.

TABLE I: ELECTRICITY USE FOR APPLIANCES AND LIGHTING FOR AN AVERAGE CANADIAN HOUSEHOLD [18]

Appliance	Appliance/ house	kWh/ Appliance	Use factor	kWh/year
Refrigerator	1	801	1.24	992
Freezer	1	614	0.56	346
Dishwasher	1	72	0.55	39
Washer	1	76	0.81	62
Dryer	1	988	0.79	780
Range	1	769	0.92	711
Other Appliances	8.98	1868	1.00	1896
Lighting(/m²)	121 m²	14.4*	1.00	1742
Total				6567

* in kWh/m²

As this study is focused in harmonic losses, the appliances dishwasher and range are not depicted, once its harmonic contents are neglected. The other appliances relevant for this study are depicted in *Table 2.*

TABLE II: OTHER APPLIANCES ELECTRICITY USE [18]

Appliance	Power [W]	Operating Hours per Month
Microwave oven	1500	10
TV	100	125
Laptop	30	240
Desktop	250	240
Vacuum	800	10

The program was simulated for the usual appliances presented in an average Canadian household respecting their period of operation during a year.

IV. RESULTS AND ANALYSIS

The technical losses analyzed in this work are divided into three segments: distribution transformer, secondary system phase line and secondary system neutral line. In this sense, a detailed harmonic active and reactive loss diagram was developed to represent the impact generated for each harmonic component per appliance into distribution system technical loss.

Concluded the simulation processes the impact caused per appliance was determined. The diagrams representing the CLF Lamps harmonic impact in active technical losses and reactive technical losses are depicted in *Fig.5-6*.

These diagrams represent the losses caused in each segment separately per harmonic component. Then, the sum of all contribution leads to the total distribution system technical loss generated per appliance.

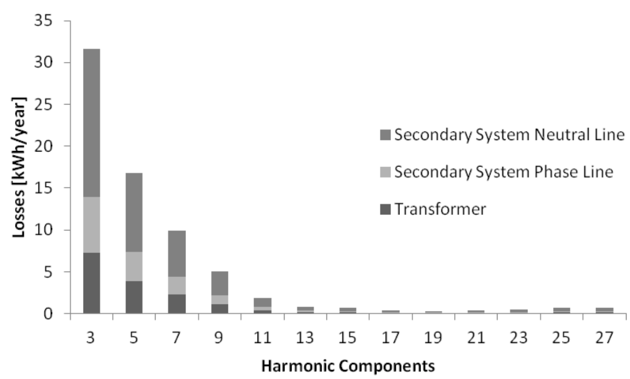

Fig. 5: Active Harmonic Losses caused by CLF Lamps in the distribution power system

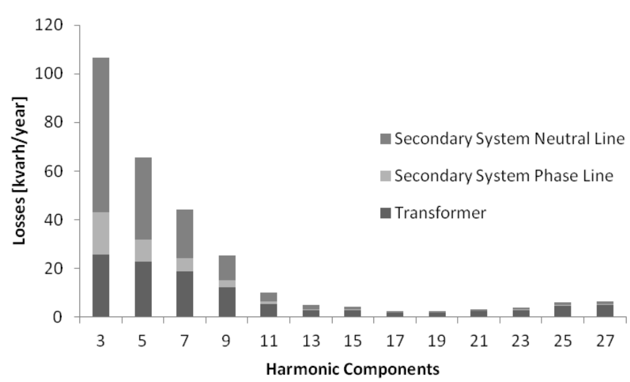

Fig. 6: Reactive Harmonic Losses caused by CLF Lamps in the distribution power system

As expected greatest losses are associated to the secondary system lines, once it has a significant impedance value. It is interesting note the losses increase starting at the 21th harmonic. This fact is associated to the impedance characteristics, and may worsen if resonance conditions are available.

Further, a general perspective of results including all appliances is presented for the distribution transformer, *Table 3*.

TABLE III: TECHNICAL LOSSES CAUSED BY HARMONICS IN THE DISTRIBUTION TRANSFORMER PER APPLIANCE

	Distribution Transformer Harmonic Losses		
Appliance	***P [W]***	***Q [var]***	***kWh/year***
Fridge	0.02	0.13	0.07
Freezer	0.02	0.11	0.04
CLF	1.09	7.43	15.89
TV	0.00	0.01	0.01
Laptop	0.19	1.75	0.45
Desktop	0.54	2.81	1.35
Washer	1.48	7.26	0.22
Dryer	0.03	0.21	0.01
Microwave	7.96	30.78	0.96
Vacuum	1.02	3.99	0.12
Total Harmonic Losses [kWh/year]			19.11

The same approach is presented in *Table 4* for the secondary system.

TABLE IV: TECHNICAL LOSSES CAUSED BY HARMONICS IN THE SECONDARY SYSTEM PER APPLIANCE

	Secondary System Harmonic Losses				
	Phase		***Neutral***		***kWh/year***
Appliance	***P [W]***	***Q [var]***	***P [W]***	***Q [var]***	
Fridge	0.02	0.05	0.05	0.17	0.25
Freezer	0.02	0.04	0.06	0.14	0.13
CLF	1.01	2.60	2.66	9.56	53.50
TV	0.00	0.00	0.00	0.01	0.02
Laptop	0.18	0.61	0.47	2.25	1.50
Desktop	0.51	0.99	1.32	3.62	4.54
Washer	1.38	2.55	3.62	9.35	0.75
Dryer	0.03	0.07	0.09	0.27	0.02
Microwave	7.42	10.79	19.42	39.62	3.22
Vacuum	0.95	1.40	2.49	5.15	0.41
Total Harmonic Losses [kWh/year]					64.36

An overview of the contributions generated by harmonic components of appliances in technical losses for a distribution system in residential level is shown in *Table 5*. These results are the ultimate goal of this work.

TABLE V: DISTRIBUTION SYSTEM TOTAL LOSSES CAUSED BY APPLIANCES HARMONIC COMPONENTS

	Distribution System Total Harmonic Losses	
Appliance	***kWh/year***	***kvarh/year***
Fridge	0.32	1.27
Freezer	0.17	0.51
CLF	69.39	285.62
TV	0.02	0.11
Laptop	1.95	10.57
Desktop	5.89	18.41
Washer	0.98	2.88
Dryer	0.03	0.10
Microwave	4.18	9.74
Vacuum	0.54	1.27
Total	83.47	330.49

V. CONCLUSION

This work highlights the impact caused by appliances on the distribution system technical losses. The results indicate the parcel of harmonic losses produced per appliance in different segments of the grid.

The increasing participation of DGs, such as the massive insertion of electrical vehicles (EV), may lead the system to even bigger technical losses. Therefore, control measures should be implemented to reduce the harm caused by home appliances harmonic components, helping the system supports its future.

ACKNOWLEDGMENT

Yuri Reis thanks the Science without Borders Program. This program, sponsored by the Brazilian government enabled the student to spend a year abroad.

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