Incorporating home appliances into a DC home nanogrid.

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Abstract. The possibility to incorporate home appliances of high efficiency into a home Direct Current (DC) nanogrid is presented. Switching power supplies made possible this fact. We present in this work an advance of the mathematical model for the switching power supplies as a part of the nanogrid, as well as preliminary results of measurements of currents in some home appliances used at home that will be used to elaborate a thorough model of DC nanogrids. We measured the consumption of meaningful loads on both Alternating Current (AC) and DC. For instance, we used an induction stove for cooking giving a loss of the 16.66\% of the maximum wattage level while in the medium wattage the loss is of the 32.72 \% (on AC) while for a laptop adapter, the loss is 3.33\%. Their respective losses operating on DC are zero.

Keywords: Nanogrids. Switching power supplies. Home appliances.

1. Introduction

In addition of being of low efficiency, the fossil energy generation \cite{1} is associated with serious problems such as environmental ones, for instance the increasing level of pollution or the greenhouse effect, among others. Due to both the growing demand of energy and the decreasing of reserves of petroleum oil, there is a risk on the electric network stability and its potential collapse; in most cases the network is mainly fed by the burning of fossil fuels and it is designed for a maximum capacity \cite{2}.

Home appliances represent the main charge of the domestic sector to the public electric network and they are used to satisfy the needs at home. According to Martinez et. al. \cite{3}, the main needs of electric energy of a home in Mexico, in accordance with their percentage of consumption are as follows:

1. Lightning, 22 \%;
2. Food refrigeration, 30 \%;
3. Cooking and food preparation;
4. Sanitary water heating;
5. Air conditioner, 19 \%;
6. Entertainment and communications (TV, 14 \%, cell phone, etc.).

Currently, with the integration of renewable sources, which are more simple and affordable \cite{4}, there exists the possibility of generating and storing energy at home. This could help with the
electric home needs, would avoid the transmission of electric energy through long distances and saving money and resources such as the Liquid Petroleum Gas (LPG) or even better, avoiding the burn of fossil fuels. In fact, the use of renewable sources allow us to incorporate home appliances of high efficiency like, for instance, for cooking or to the food preservation [5], diminishing the consume of electric energy coming from the network.

New concepts have been developed around the electric network such as micro- or nano-grid for the electric system decentralization [6–10]. A nanogrid is composed by a sector which generates electric energy, commonly a source of renewable energy, energy storing devices, charges and the control and monitoring systems. The nanogrid can be connected to the public electric network or operate in an isolated way, presenting the last state, a better performance, whenever the different stages of energy transformation are reduced [5]. The nanogrid working on DC has a bus that fed different charges and can be connected to the public electric network by means of an inverter or a rectifier diode [11]. As far as the microgrid is concerned, this is usually defined as a set of consumers that generate and store energy in a coordinate way to have reliable and predefined exchange of energy with the rest of network distribution system through a common point coupling [12]. We leave the discussion of this kind of systems aside.

Within the power electronic systems, the voltage and the power are possible regulate and isolate them by means of a switching power supplies either by a buck or a boost converter depending on the necessity. The AC is rectified to DC or equivalently to a direct voltage $V_d$, without the need of a transformer. This is the key to incorporate the home appliances, as well as the range of the voltage for the nanogrid which internally operate with DC, such as electronic devices of communication or entertainment [13].

In this work we introduce and analyze a particular nanogrid system used at home and present some preliminary results. An outline of this work is as follows: In section II we present the system and the model to be analyzed. In section III we present some measurements made in the systems. In section IV we discuss preliminary results. Finally in section V we present our conclusions.

2. The model.

Let us consider the usual buck converter, whose schematic circuit is presented in Fig.1. The transistor works as a switching system (turn on and turn off) which minimize the power loss. The equivalent circuit is shown in Fig. 2 where the transistor is substituted by a switch, obtaining a model for a home appliance. By applying Kirchhoff’s law for voltage, we obtain the equations systems:

\begin{align}
V_L + V_C &= V_d \\
-V_C + V_0 &= 0,
\end{align}

where

\[ V_L = L \frac{di_L}{dt}, \]
\[ V_0 = R i_R, \]
\[ V_C = \frac{Q_C}{C}, \]

being \( V_L \) the voltage in the inductance, \( V_C \) the voltage in the capacitor, \( i_R \) the current in the resistance, \( i_L \) the current in the inductance and \( V_0 \) the voltage in the resistance. In the nanogrid the buck converter is directly connected to the DC source. In order to represent the switching, \( V_d \) is modeled as
\[
V_d = \begin{cases} 
120 \text{ VDC} & \text{for } 0 < t < T_{ON} \\
0 & \text{for } T_{ON} < t < T,
\end{cases}
\]

where we assume a period \( T \) which is divided into two periods \([0, T_{ON}]\) and \([T_{ON}, T]\). We obtain an ordinary differential equation of order two, which, in terms of the frequency \( \omega_0^2 = 1/LC \) and the damping \( \alpha = 1/2RC \), can be expressed as
\[
\frac{d^2 Q_C}{dt^2} + 2\alpha \frac{dQ_C}{dt} + \omega_0^2 Q_C = \frac{V_d}{L}.
\]

The homogeneous solution, \( Q_{CH} \), to Eq. (4) is given by
\[
Q_{CH}(t) = Ae^{m_1t} + Be^{m_2t}
\]
where
\[
m_1 = -\alpha + \sqrt{\alpha^2 - \omega_0^2},
\]
\[
m_2 = -\alpha - \sqrt{\alpha^2 - \omega_0^2}.
\]

In order to obtain the particular solution, we resort to the Fourier analysis, where we will implement a method to analyze the harmonics \([14]\) and will make a complete analysis of the system.

3. The system.
The home DC nanogrid system we analyzed, is composed by a set of 10 batteries NorthStar model NSB 170FT Red Battery whose operation ranges are from 100 to 140 VDC, it is fed by 5 solar panels of 250 watts each; one panel feeds 2 batteries operating to 24 VCD. The nanogrid has its charge controller as it is shown in Fig. 3. Although there are two optional ways for operating the nanogrid: by interconnecting with Electricity Federal Commission (CFE) through a bidirectional converter \([15]\) (inverter/rectifier) or the isolated system, we have opted for an isolated system. Is this way, it is only taking energy from the grid through the rectifier (batteries charger, 120 VAC/120 VCD) in rain season, when there are many days cloudy and rainy. With this system, we used home appliances in which their operation is based on switching power supplies or they use universal electric motor. For cooking, it is incorporated an induction stove SISOLAR of 3600 watts of power and four surface cooking elements and a blender operating at 600 watts, 60 Hz and 120 VAC. It is also incorporated an AC/DC adapter laptop working at input 100-240 VAC 60 Hz 1.2 A and some others devices whose electric energy consume is minimal such as a battery charger of 28 watts. We measured the electric current, alternating and direct of each home appliance, the results are shown in Table 1, the measurements correspond the operation regime of AC and DC as well as the standby state.
Figure 3: The home DC nanogrid configuration.

Table 1: Electric current consume in each home appliance.

| Home appliance     | DC (A) | AC (A) |
|--------------------|--------|--------|
|                    | ON     | OFF    | ON     | Standby |
|                    | OFF    | Percentage |
| Lap Top            | 0.3    | 0.0    | 0.3    | 0.01    | 3.33%   |
| Battery Charger    | 0.1    | 0.0    | 0.2    | 0.0     | −−−     |
| Blender            | 2.7    | 0.0    | 2.4    | 0.0     | −−−     |
| Induction Stove    | 9.1    | 0.0    | 10.8   | 1.8     | 16.66%  |

4. Analysis and outlook.
We observe that the electric energy consume of the induction stove is remarkable different in the standby state from the operation state when it is connected to AC system (in the standby state there is an electric energy consume), but when the induction stove is connected to home DC nanogrid, the energy consume is simply zero in the standby state. Of course, this is due to the presence of a capacitor with current \( i_C = C \frac{dV(t)}{dt} \) where the supply voltage is \( V(t) = V_M \sin(\omega t + \theta) \). The function of the capacitor is of being an Electromagnetic Interference Filter (EMIF) [16] which is a permanent load AC system. Whenever the system operates on DC, the consume is zero, since \( \frac{dV}{dt} = 0 \). The current measure in one surface cooking element in the induction stove is of 10.8A giving the maximum wattage level of 1000 Watts. At the medium wattage level, the measure current is 5.5A, this corresponds to an average usage of the induction stove. Note that the gap between AC (rms measurement) and DC current is 10.8 – 9.1 ≈ 1.8A. For the AC/DC adapter of the Laptop the measured current at standby state is 0.01A.
5. Conclusion.
Currently there is not home appliances operating with DC in the local market, most home appliances are designed to operate in the AC regime. Nevertheless, due to the switching power supplies, home appliances can be incorporated into the DC nanogrid. We consider that it is important to make more technologic advances to incorporate renewable sources of energy at home like as the adapting of home appliances into a DC nanogrid. One of the objectives in this work is to analyze the way in which it is diminished the use of fossil fuels as well as the dependence on the public electric network. Nowadays, thanks to the power electronic this is possible, given as a result a decrement in the costs and a growing in the efficiency. The nanogrid can be incorporated into the public electric network (CFE) allowing the interchange of electric energy by means of a bidirectional converter (inverter/rectifier). The analysis and discussion of this new system will be discussed in a separated communication.

The appliances used in this study are not modified, which represents a easy and cheap way to incorporate into the home DC nanogrid. As far as the laptop is concerned, its energy saving is rather small, while for the induction stove the energy saving ranges from 16.66% for a maximum wattage level to 32.72% at the medium wattage level.

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