A SINGLE-PHASE DUMP LOAD FOR STAND-ALONE GENERATING UNITS WITH INDUCTION GENERATOR

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Abstract **– This paper deals with the analysis of an electronic load controller – also known as dump load-, in order to improve its regulating behavior in stand-alone generating systems. The study focuses on a topology dedicated to single-phase micro-grid. The solution is analyzed from the current harmonics injection point of view, through simulations and experimental essays.**

Keywords**:** *renewable energy induction generator, dump load, current harmonics.*

1. INTRODUCTION

The actual tendencies on energy markets – due to the rapid depletion and enhanced costs of conventional fuels –, combined with growing concerns about the environment, have led to an important technical progress in the field of renewable energy systems. Among the renewable sources, hydro and wind remain the most competitive, mainly in stand-alone applications.

For autonomous power plants, the induction generator (IG) represents the most attractive solution due to its suitability for different applications such wind and micro-hydro. Its characteristics (brushless construction, low maintenance and low capital cost) give it an important advantage over the synchronous generator. Mainly, the three-phase squirrel-cage machines are employed as generators. However, in rural and isolated places with installed powers bellow 10 kW single-phase networks are employed. A need therefore arises for the use of single-phase induction generators in these systems [1]. Although all single-phase induction motors can be operated in the generator mode, they may not give the best performance since they have been designed for optimal motor operation. Another drawback is that they cannot exceed 3kW, because such a machine is physically big and expensive.

On the other hand, three phase induction machines are available in a wide power range and their use for supplying single-phase micro-grids is of real interest. In order to do that, some adaptations are required. Over the years, several topologies have been developed. One of them proposes the connection of the load impedance in parallel with the excitation capacitance, while only two stator phases are involved in the case of a star connected machine [2]. Other solution implies the use of a single capacitance for self-excitation, emphasis being placed on the Steinmetz connection, with the load impedance connected on a different phase then the excitation capacitance.

Assuming that we have a three-phase IG supplying a single-phase micro-grid, the problem that needs to be solved is the frequency regulation, and to maintain the three-phase voltage system symmetry. Inherently the load of an energy source is supposed to be randomly variable. Symmetry of the three-phase is then affected. The control is obliged to maintain the load constant to avoid the above-mentioned drawbacks.

At a first look, a turbine governor seems an appropriate solution - from the efficiency point of view -, because by maintaining the produced power in range with the demanded one eliminates the need for an additional circuit in the system. However, such a configuration is expensive and inefficient for low-power applications (few tens of kW). As the mechanical constants are high, the regulating process is slow and the overall cost significant. Also, the system's response under suddenly load switching is poor, resulting in voltage sags and frequency deviations.

The other solution is to use a load controller, which feeds a dump load, enabling the total power supplied by the generator to match the sum between the consumer's loads and dump load. As the active power balance is achieved, the frequency is satisfactory regulated. The authors have studied several control strategies for different generators [5].

Several topologies for electronic load controllers have been developed over the years. Modern and cheaper solutions use an uncontrolled bridge rectifier feeding a resistance through a chopping power transistor whose duty cycle is controlled in order to modify the active power. Therefore, the main advantage is the use of one controllable device only. This solution is available for three-phase IG feeding three-phase loads. The topology can be easily modified to match the requirements of a single-phase system, by replacing the three phase uncontrolled bridge with a similar single-phase one. This aspect is discussed and analyzed in this paper.

However, by using such a configuration current harmonics are injected into the system. The harmonics level depends on the dump load's charging. Moreover, the circuit's Power Factor (PF)

is directly influenced by the dump load's harmonics injection. These quality issues have been studied in [6].
The importance of the harmonics content study is related to the dump load's current harmonics injection influence on the generated voltage shape in the case of rather small power generator systems (in the range of several kW).

2. DUMP LOAD CONFIGURATION

The dump load's electrical diagram is presented in fig.1. It consists in a single-phase rectifier bridge and a DC chopper. The active power flow is controlled by the duty cycle of the Pulse Width Modulation (PWM) signal that drives the transistor T (particularly an IGBT).
Both mentioned above solutions are analyzed and simulations are made in order to yield the most effective one from the harmonics content point of view.

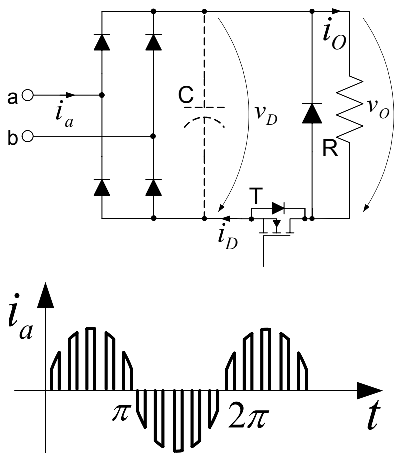

Figure 1. Dump load's electrical diagram

In the followings, the theoretical approach for the dump load without smoothing capacitor is presented.

The RMS rectified voltage is

$$V_D = V_m / \sqrt{2} \tag{1}$$

where: V_m - peak input voltage.
The active power is given by the dumped power on the resistance R. The output RMS voltage is:

$$V_{O\,RMS} = V_D \sqrt{k} \tag{2}$$

where: k – PWM duty cycle.
Therefore, the active power dissipated on the resistance R, is

$$P_O = \frac{V_O^2}{R} = \frac{k \cdot V_m^{\ 2}}{2 \cdot R} \tag{3}$$

The input RMS phase current at the rectifier-bridge input, is equal to the output current (I_O), :

$$I_a = I_O = \frac{V_O}{R} = \frac{V_m}{R}\sqrt{\frac{k}{2}} \tag{4}$$

The apparent power at the dump load leads has the following expression:

$$S = VI = \frac{V_m^{\ 2}}{2R}\sqrt{k} \tag{5}$$

where: V is the RMS line-to-neutral voltage(sinusoidal).
Therefore, the circuit's PF is,

$$PF = \frac{P}{S} = \sqrt{k} \tag{6}$$

Also, for a sinusoidal input voltage (harmonic free), the active power is supplied only for the fundamental component of the current, and so the PF can be expressed as:

$$PF = \frac{I_1}{I}\cos\varphi_1 \tag{7}$$

where: I_1 - fundamental RMS input line current;
I - RMS input line current;
φ_1 - displacement angle.
The line current Total Harmonic Distortion (THD) is:

$$THD_i = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} = \sqrt{\left(\frac{\cos\varphi_1}{PF}\right)^2 - 1} \tag{8}$$

The displacement angle for the fundamental component can be approximated as $\varphi_1 = 0$ (resistive load) so the THD formula can be simplified as,

$$THD_i = \sqrt{\frac{1}{PF^2} - 1} = \sqrt{\frac{1}{k} - 1} \tag{9}$$

The two THD and PF according to k are represented in Fig. 2.

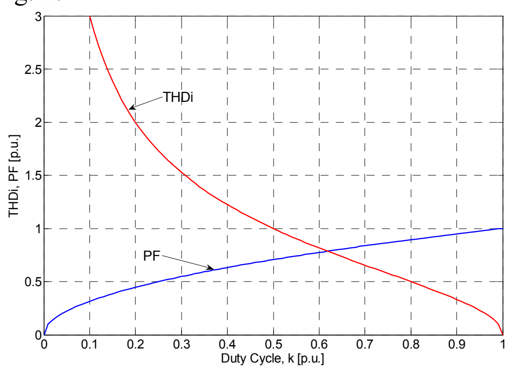

Figure 2.THD and PF vs. duty cycle (k)

3. SIMULATION AND EXPERIMENTAL RESULTS

The proposed system has been modeled and simulated by using the Matlab\Simulink environment. Fig. 3 shows its block diagram. The configuration includes a three-phase voltage source (which replaces the generating machine from the experimental bench), a rectifier bridge, a chopper, the dumping resistance and measurement.

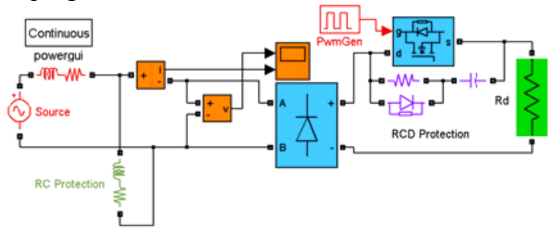

Figure. 3. Simulink block diagram

They have the following parameters:
- the single-phase voltage source:
  - phase voltage V=220/50Hz,
  - internal resistance, inductance R=0.5Ω, L=1mH
- the dumping resistance R=54Ω
- smoothing capacitor 2000µF
- PWM frequency 1 kHz

The simulations were carried out following in parallel two main directions: with and without filtering (smoothing) capacitor, in order to yield the most suitable one.

The total power that can be absorbed by the dump load is approximately 1kW.

The same parameters and working conditions were employed for the experimental part. Data acquisition was required, so the DS1102 DSP Controller Board with Extension Box was employed.

First, simulations are carried out. For a duty cycle of 30%, the input currents (without and with smoothing capacitor) are presented in Fig. 4. As mentioned in section 2 the dump load introduces high current harmonics, which distort the waveform.

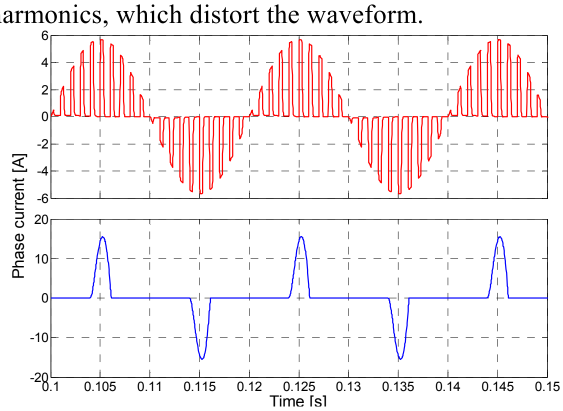

Figure 4. Phase currents without and with smoothing capacitor

Next, the experimental results are presented, which show that the waveforms obtained above are similar to the ones sampled with the acquisition board. In Fig. 5 the phase current without smoothing capacitor is shown.

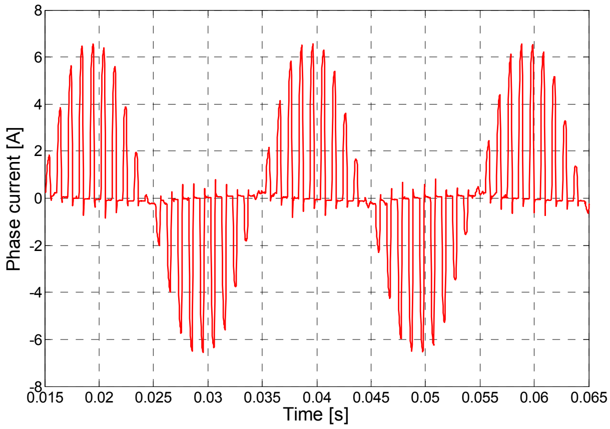

Figure 5. . Phase currents without smoothing capacitor (experimental)

The chopper's command uses different duty cycles in order to get an accurate idea about the system's behavior (harmonics content). The following figures (Fig. 6 and Fig. 7) show the harmonic content for three duty cycle values: 30%, 50% and 80%. As for the different duty cycle values, it can be observed that the harmonic distortions decreases when the duty cycle's value increases. Therefore, from this point of view, the dump load has to operate at high power, but it has to be taken into account the negative outcomes that the harmonic currents may produce into the system, especially on the voltage wave shape.

In Fig. 6, the situation without smoothing capacitor is depicted. The significant current harmonics (over 1% of fundamental) are the 19^{th}, 21^{st}, 39^{th}, 41^{st}. Their source is the PWM frequency. The even harmonics are not present due to the half-wave symmetry.

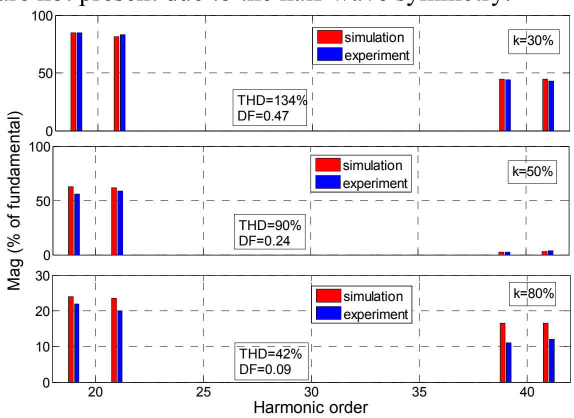

Figure 6. Current harmonics content for different duty cycles - without smoothing capacitor

When a smoothing capacitor is used, low order harmonics (3^{rd}, 5^{th}, 7^{th}…) become important, compared with the previous situation, as shown in Fig. 7. Thus, the Distortion Factor (DF) increases significantly. Nevertheless, using a smoothing capacitor ensures the attenuation of the high order harmonics, which are significant in the other situation. As for the current THD, its value increases, especially when we have a big duty cycle (for k=80%, the THD increases from 42 to 92%).

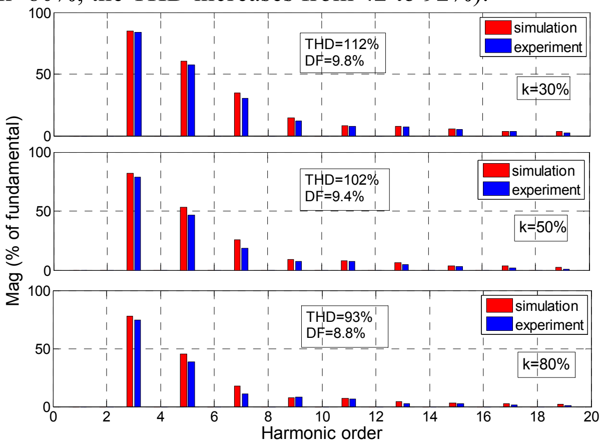

Figure 7. Current harmonics content for different duty cycles - with smoothing capacitor

Low order harmonics are much more harmful then the high order ones, in such systems (autonomous ones supplied by induction generator). Furthermore, the presence of capacitor banks ensures the attenuation of the high order harmonics.

We can conclude that the most suitable dump load configuration is the one without smoothing capacitor, although it can lead to circuit resonances. Therefore, the system's AC capacitors and inductive loads play an important role in the resonance phenomena.

4. CONCLUSIONS

In low power stand-alone systems, the use of dump load proves to be a profitable solution for frequency regulation. The studied dump load structure ensures a simple and robust control strategy. The main drawback is the current harmonics injection, which affect the voltage shape and can lead to resonant phenomena.

As simulations and experimental results show, the configuration without smoothing capacitor is more suitable then the one with capacitor because the current THD and DF are lower, also the low order harmonics are less significant too. When the chopper duty cycle increases, the harmonics content decreases, thus high duty cycles are more convenient.

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