LOW POWER GENERATING SYSTEM, SIMULATION AND ANALYSIS

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Abstract **– Most distributed generating systems (DG) are not new in a technological respect, they are receiving increased attention today because of their ability to provide backup power, improved power quality, and ancillary services to the power grid. This paper presents a simulation and a rigorous analysis for low power distribution 5 kW using specialized electric and electronic simulation software. Most important part of the paper presents the simulation of power electronics that are able to convert the power generated into useful power that can be directly interconnected with the utility grid and/or can be used for consumer applications. One presents specific matters related to the simulation of an AC-DC-AC converter and respectively of a filtering coil for the ripple appearing in the output current of the PWM inverter. Significant aspects with respect to the behavior of the simulated components for various loads are revealed. A PSpice model of the entire DG system was conceived in order to simulate the waveforms for voltages and currents. One emphasizes the good agreement with the IEEE standard 1547/2003, used for the interconnecting distributed resources with electric power systems.**

Keywords: *Distributed generating (DG), power converter, inverter, DC Link, Grid.*

1. INTRODUCTION

Distributed generating (DG) is an emerging concept in the electricity sector, which represents good alternatives for electricity supply instead of the traditional centralized power generation concept.
Generally, the term Distributed or Distributed Generating refers to any electric power production technology that is integrated within distribution systems, close to the point of use. Distributed generators are connected to the medium or low voltage grid.
DG technologies require specific power electronics interface that need to be capable to accepts power from the distributed energy source and converts it to power at the required voltage and frequency, e.g. [1].

2. PRINCIPLE SCHEMATIC OF THE DG SYSTEM

A basic block scheme to represent static converter used in distributed generating systems is shown in Fig. 1. The static power converter converts the electric energy from the unconventional source to the parameters required by grid, e.g. [2], [3], [4].

Using PSpice, a program was conceived to examine issues related to the operation of the conversion system and the possible problems that might arise.
This schematic contains the following elements:

- Renewable source represented by the three-phase generator
- Three-phase rectifier used to perform the conversion AC to DC energy
- DC-link who supplies the single-phase inverter (provides the connectivity rectifier - inverter)
- Single phase PWM inverter
- LC passive filter, in order to eliminate the current ripple generated by inverter
- Grid
- Load (linear).

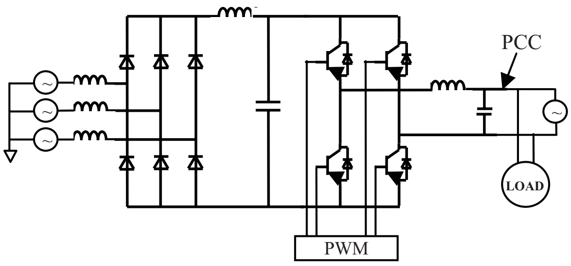

Figure 1: Basic scheme for low power generating systems

3. SCHEMATICS SIMULATION FOR A LOW POWER DISTRIBUTED GENERATING SYSTEM

3.1. Three Phase Generator

The three phase generator was simulated through a Y connected three-phase AC supply that provides 50 Hz sinusoidal wave and a phase difference of 120°. The voltage's pick value is 240 V. The neutral wire was connected to the ground between a high resistance value (1,000 kΩ). Fig. 2 depicts the scheme of this generator.

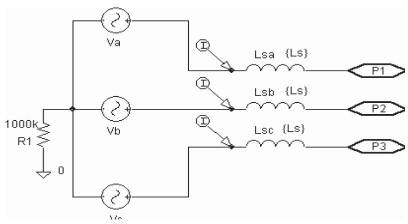

Figure 2: Three-phase generator supply

3.2. Inductor Filter

The inductor filter is connected between the generator and rectifier, and it is used to filter the harmonics generated by rectifier. For each phase one uses 113 μH inductors and respectively 20 Ω resistances as wire parameters.

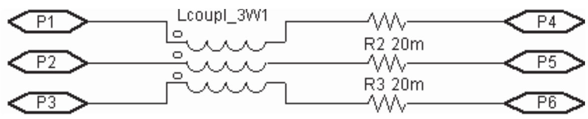

Figure 3: Inductor filter

3.3. Three-phase rectifier

The three-phase rectifier is a classic self-commutated rectifier with diodes. The rectifier's scheme is shown in Fig. 4. The diode model selected from simulation program library has characteristics identical to the real model.

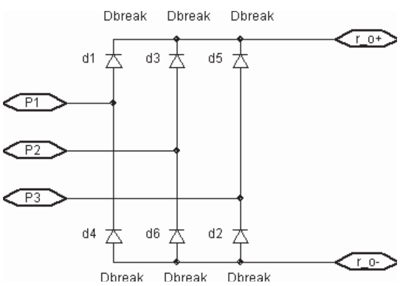

Figure 4: Three-phase rectifier with diodes

3.4. DC Link Filter

The DC link filter is important for the static converter AC-DC-AC, as it provides the interface rectifier-inverter and supplies the single-phase inverter.

In the DC link, Aluminum electrolytic capacitors (connected in series and/or in parallel) are usually used:

(a) to compensate the difference between the power requirement of the inverter (whose mean value is constant in steady-state operation) and the output power of the input-rectifier bridge varying with two or six times the mains frequency;

(b) to supply the input current of the inverter with pulse frequency;

(c) to reduce the spread of current harmonics with pulse frequency into the mains;

(d) to take in the demagnetization energy of the drive (e.g. induction machine) in case of an emergency shutdown of all converter transistors;

(e) to supply transient-power peaks;

(f) to protect the inverter from transient peaks of the mains voltage.

The DC link capacitor's selection criteria are: rated voltage, capacitance, RMS current and resonance frequency, e.g. [6], [7], [8].

Considering them one selected a capacitor with capacitance of 1,880 μF. The capacitor's real parameters are resistance R_{Lf} and inductance L_d.

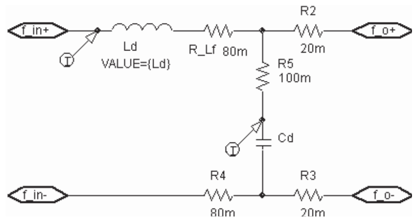

Figure 5: DC link filter scheme.

In Fig. 6 a) one can see that the simulated rectified voltage has a 400 V constant value. The second waveform represents the current in the DC link capacitor's. The third and the fourth waveforms are the currents waveforms given by the influence of the rectifier and inverter.

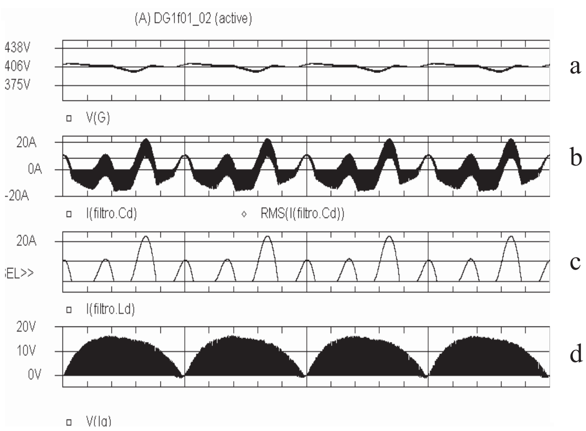

Figure 6: The waveforms in the dc link
(a) rectifier's voltage; (b) current waveform in the capacitor
(c) rectifier's current (d) inverter's current

This simulation yielded the RMS values of the current through the capacitor for different values of the active power injected by inverter.

P [kW]	0.5	1	1.5	2	2.5	3	4	5
I_dRMS [A]	4	5	6.5	8.5	10	11.8	15	18.5

Table 1: RMS current value in the DC link capacitor

As the DC link capacitor selection is an important issue, one performed a Fourier analysis of the currents through the DC line filter, e.g. [6], [7], [8].

One can see that, owing to the rectifier's influence, the significant harmonics are those of order 4 and 6 and respectively the DC component. Moreover, due to the single-phase inverter's influence one could notice significant harmonics of order 2 and multiples of 20 kHz, yielded associated to the semiconductor elements' switching.

Fig. 7 depicts the harmonic spectra of 3 currents: the first flows through the DC link, the second is due to the rectifier's switching and the third is due to the inverter's switching.

The simulation's focuses on the influence that each of the static converters exhibits over the DC line.

The current flowing through the DC link presents significant harmonics of orders 2, 4 and 6, with peak values exceeding 15 A.

The harmonics yielded by rectifier are represented in the second graph from Fig. 7. Here one can notice, along with even harmonics, a significant DC component, of almost 10 A.

The third graph from Fig. 7 reveals the influence of the single phase inverter, responsible for the second order harmonic with a peak value of approximately 10 A that appears in the DC line filter.

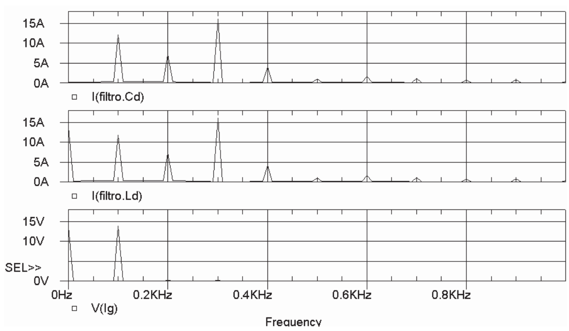

Figure 7: Harmonic spectrums from the DC line

Fig. 8 depicts the harmonic spectra from the DC line's filter within the range [0…22 kHz]. Significant harmonics of 20 kHz can be noticed, with almost 5 A peak values, generated by the inverter's switching phenomenon. These harmonics occur at frequencies multiple of 20 kHz but the magnitude decreases considerably when the harmonic order increases.

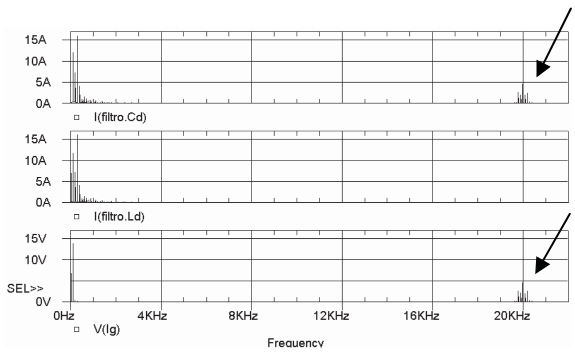

Figure 8: Harmonic spectra from the DC line generated by the inverter's switching phenomenon

3.5. Single-phase inverter

To simulate the single-phase inverter one used two bidirectional switching poles whose switching elements are represented by PWM-controlled switchings.

The values specific for the switching are R_{ON} =0.035Ω; R_{OFF} = 100 kΩ; V_{ON} = 0.8 V; V_{OFF} = 0.5 V.

The control signal is provided by the PWM control, obtained through the comparison of a triangle-shaped signal with a sinusoidal one. The control signal is depicted by Fig. 10.

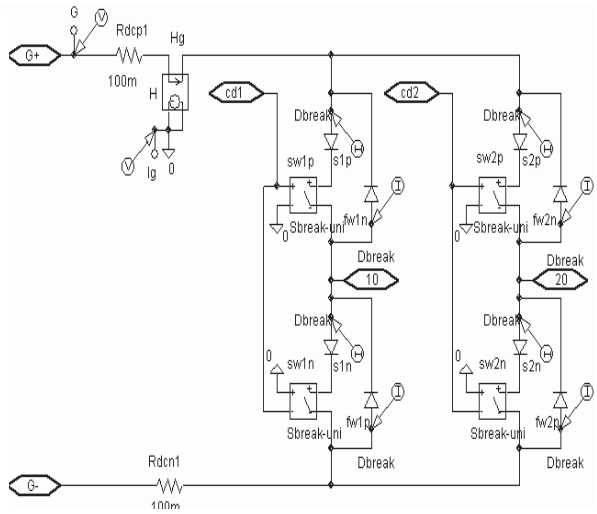

Figure 9: PWM single-phase inverter scheme

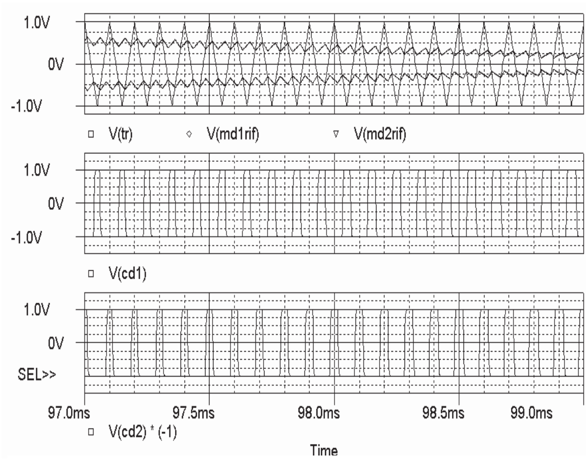

Figure 10: Triangle-shaped signal, reference signal and control signal

3.6. LC Filter

The *LC* filter is designed to filter the current generated by the single-phase inverter, such that the current ripple is considerably reduced. The resonance frequency is $f = 2,400$ Hz.

$$f = \frac{1}{\sqrt{LC}} \tag{1}$$

The value considered for L when calculating the capacity contains the value of LC filter's inductance and the value of the network inductance, presented below.
Fig. 11 shows the waveforms corresponding to the current at inverter's output and respectively to the current filtered by the LC filter. One can notice that the current ripple is considerably reduced.

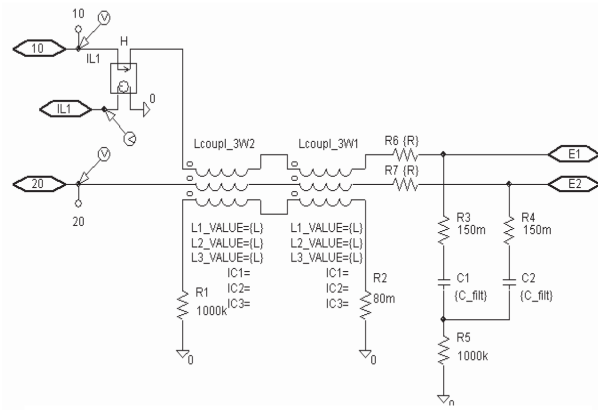

Figure 11: PSpice electric scheme of the LC filter

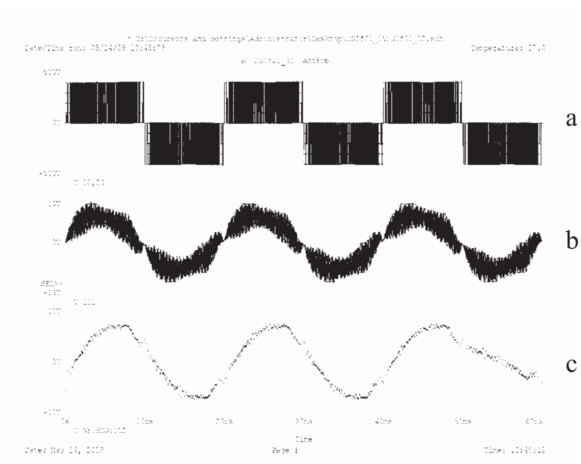

Figure 12: Waveforms of the voltage supplied by inverter, un-filtered and filtered current

3.7. Single-phase supplying network („Grid")

The supplying network consists in a single-phase source of AC voltage with the parameters: 50 Hz frequency, 311 V magnitude and the inductor L_{se} of 50 µH inductance.
The link to the null wire is performed through a significant resistance value (1,000 kΩ). The network has a common coupling point with the conversion part through the LC filter and load. The output voltage and current waveforms are depicted by Fig. 14.

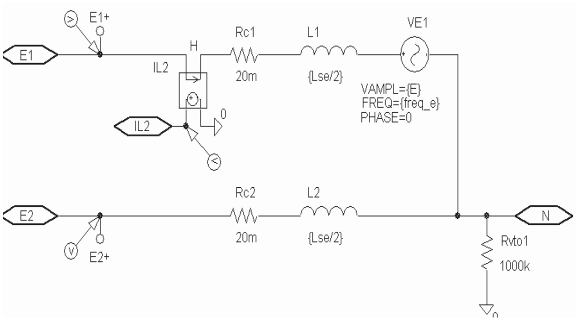

Figure 13: Single phase supplying network

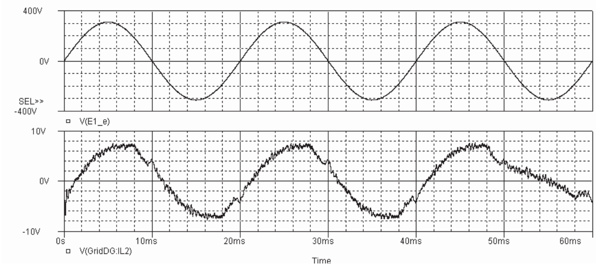

Figure 14: Voltage and current measured at the supplying network

3.8. The Load

The load is connected to the common connecting point (PCC). It is represented by the linear resistor R_1 with the resistance value.

$$R_1 = \frac{0.5 \cdot E^2}{P_{load}} \tag{2}$$

where E - is the network supplying voltage and P_{load} is the power absorbed by consumer.
The load is connected to the circuit with a delay of 50 ms, due to the pulse generator V_1 that provides the closing control signal of both switches. To provide a reliable grounding, a high resistance is used.

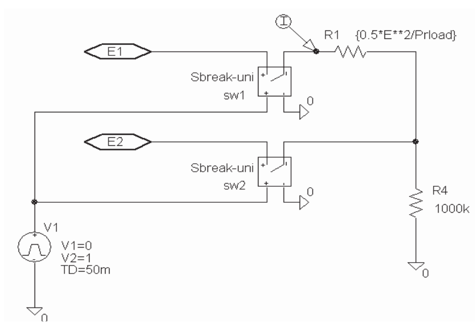

Figure 15: PSpice schema electric for the load

The waveform of the current absorbed by the load is depicted by Fig. 16.

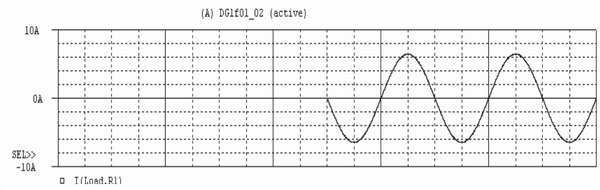

Figure 16: Load current waveform

An analysis was also performed over the voltage generated by inverter and respectively over the network voltage (considered as phase reference), e.g. [9], [10], [11], [12].
Table 2 presents the phase and magnitude for various powers of the power absorbed by consumer.

P_{Load} [kW]	U_{grid}	φ_{Ugrid} [°]	U_{inv} [V]	φ_{Uinv} [°]
0.5	311	0	311.5	0.25
1	311	0	312.5	0.265
2	311	0	313	0.47
3	311	0	314	0.6
4	311	0	315	0.83
5	311	0	316	1.09

Table 2: Phase and peak value of the voltage generated by inverter and network voltage

From Table 2 one can notice a small active power absorber by consumer (0.5 kW). The phase-difference between the network voltage and the voltage generated by inverter is practically insignificant, reaching to 1.09 electric degrees for a power absorbed by consumer of 5 kW, e.g. [12].

4. CONCLUSION

The studies show that DG can have a significant impact in a typical low power network.
To understand the operating principle of a distributed generation system and to be able to perform an analysis of the problems that might appear owing to various operating regimes, one performed a PSpice simulation.
Using the simulation results one could issue a study over the static converter from the distributed generation system of low power. One analyzed the values of the current that flows through capacitor from the DC line of the AC-DC-AC static converter for various values of the active power injected into system.
One could draw the conclusion that for an injected power of 5 kW the RMS value of the current flowing through the DC filter can reach a significant value (18.5 A), required for a proper selection of the type of capacitor to be used in this system.
After the analysis over the inverter's output current waveform one can also notice that, when the *LC* filter is used at inverter's output, the ripple from the current generated by inverter is reduced e.g. [13], [14].
The results gathered by Table 2 reveals that the generation system is in agree with the presents standards relative to the synchronization with the electric network, as the phase difference between both voltages do not exceed 2 electric degrees, e.g. [15], [16].
The results reveals that power electronics used in DG have important contribution for improvement reliability and power quality.

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