PSPICE - Based Simulation Setup for Genetic Algorithm - Aided Design of Power Converters

Adriana Sîrbu, D. Alexa, D.- M. Dobrea, I. Cleju
Faculty of Electronics and Telecommunications
Technical University "Gh. Asachi" Iaşi

Abstract – **In this paper we propose a PSPICE-based setup for genetic algorithm – aided design of power converters. This approach aims at providing the possibility of taking into account various criteria (electrical and non-electrical) to improve the design, taking full benefit both of the power of evolutionary computation and the complexity and versatility offered by PSPICE simulation environment. The simulation setup built around the PSPICE kernel is described. A case study dealing with the GA design of rectifiers with near sinusoidal input current is commented.**

I. INTRODUCTION

In general, the design of power converters is an elaborated task, which involves a large number of various design variables, together with quite severe restrictions imposed by standards and fabrication/maintenance costs.

Currently, traditional approaches circumvent this complexity by neglecting several variables, focusing mostly on the electrical behavior of the system. Still there are cases when circuit working principle requires a tradeoff between conflicting requirements imposed by different aspects/points of view of the functioning.

The possibility of taking into account most, if not all, the imposed parameters would result in reducing the effort during the hardware experiments

Modern optimization techniques could offer a valuable tool in the attempt to solve complex design requirements. Among these techniques, genetic algorithms (GA) proved to be a more and more agreed alternative solution.

GA have been used for example in line current harmonic reduction in a PWM-type ac/dc buck-type converter, [1].

A new approach for the passive filter design of the ac/dc rectifier is proposed in [2], allowing, for some specific cases, an improvement of the power factor from 0.64 to 0.92 together with an improvement of the total harmonic distortion (THD) factor from 120% to 40%. The GA engine was coupled with MATLAB for the simulation of the power system.

An evolutionary-programming-based method for designing robust and computationally efficient adaptive bandpass filters for generating current references in active power filters is described in [3]. The digital filtering approach has the following advantages: selective bandpass response, efficient attenuation of specific harmonic components, capability to handle typical frequency alteration, small number of multiplications, and structural simplicity, together with practically no prior knowledge of the electricity distribution network and its loading characteristics for the design of the current reference generator. The authors report, in an illustrative example, that the total harmonic distortion of an artificial current waveform was reduced from 36.7% to less than 3.7% within the line frequency range 49–51 Hz.

In [4], a specialized software tool was developed to encapsulate the GA optimizer engine, a JAVA graphical user interface and the steady-state algebraic analysis equations, coded in FORTRAN. The authors report for example that a cost reduction of approximately 15% was reached compared to a previous design obtained following a traditional design methodology, where a choice of switching frequency and boost inductance was left to the designer's intuitive understanding of the problem.

The objective of this paper is to propose a complex setup for the GA-aided design of electronic systems, with a particular focus on power converters. The simulation environment embeds a GA optimization engine, written in C++, and the PSPICE circuit analysis kernel.

The organization of the paper is as follows Section II presents basic principles of GAs and implementation details. In Section III the simulation environment is described. The next section discusses a case study dealing with the GA design of rectifiers with near sinusoidal input currents. Conclusions are drawn in Section V.

II. CHARACTERISTICS OF GAs

GAs represent a family of adaptive, stochastic and global computational models inspired by the biological principles of evolution, [5], [6]. Specific for these type of algorithms is the fact that the search process manipulates not just one potential solution to a problem, but a collection of such potential solution (individuals or chromosomes) which form a population.

Each individual is an encoded representation of all the parameters that characterize the solution. It has an associated value (fitness) which is a measure of its performances.

To evolve individuals with better fitness, the GAs use genetic operators (crossover and mutation) and special selection mechanisms, ensuring that better solutions have a higher chance to produce offsprings inheriting their parents beneficial characteristics. Different convergence criteria can be formulated, as for example: in terms of number of generations of evolution, in terms of ratio between the minimum and maximum of the individual fitness compared with a given threshold.

The basic structure of a GA is presented in Fig. 1.

begin
  assign t ← 0;
  randomly generate initial population P(t)
  evaluate P(t)
  while *ending criterion not fulfilled* ***do***
    begin
      assign t ← t +1
        select individuals (parents) from P(t-1) in P(t)
        mate selected individuals
        mutate offsprings
        evaluate P(t)
    end
  end

Fig. 1. Schematic representation of a GA

III. SIMULATION ENVIRONMENT SETUP

In order to implement the genetic algorithm we have adopted a philosophy inspired by GALib, a C++ library for genetic algorithms objects, [7]. The genetic algorithm was developed using the C++ Code Composer compiler facilities.

The designer should appropriately choose the class defining the chromosome representation and then the genetic algorithm class, which uses the appropriate objective function. A container for genomes (individuals) with suitable defined operators (initialization, mutation, crossover, elitism) was defined to implement the population and on it, the selection schemes operate. Different crossover methods (one point, two and three points), as well as different selection schemes: Rank Selection, Roulette Wheel Selection, Tournament Selection, Stochastic Uniform Sampling Selection, Stochastic Remainder Sampling Selection and Deterministic Sampling Selection, [5],[6], have been implemented.

Different stopping criteria can be chosen, such as: evolution over a prescribed number of generation, the condition that the ratio between the maximum and the minimum values of the individual fitness exceeds a specified convergence value (in the case of maximization of the fitness) and so on.

In order to perform GA optimization of power converters design, different solutions have been proposed din literature, [1]-[3]. The main trends so far are to use dedicated software for the analysis of the converter or MATLAB simulations as tools for circuit functioning simulation. Both solutions have their merits, but we consider that our approach, namely to use the PSPICE kernel as an analog simulator in a built around environment is better as it provides valuable details for circuit specific analysis.

Taking advantage of the experience in organizing complex simulation experiments, [8], a special simulation environment, developed in C++ language, built around the PSPICE kernel, was designed to perform GA-aided design of power converters. The simulation setup is able to provide parametric batch analysis, collect data relevant for the transient and steady-state behavior, perform digital signal processing, allowing thus the developing of complex objective functions for the GA optimization.

Basically we intervene in the *evaluate P(t)* statement of the GA algorithm, outlined in Fig.1, designing an appropriate objective function able to process results from associated PSPICE simulation in evaluating the individual fitness.

The algorithm developed for supervising and processing the simulation devoted to the power converter functioning with the assigned design parameters is included in the function evaluating the fitness of each individual, see in Fig. 2.

function Objective (Genome& g)
    assign genome resulted values to the circuit parameters;
    create .cir PSPICE *file*
    execute PSPICE *kernel to simulate the converter*
    extract analysis relevant results
    calculate fitness
  return fitness

Fig. 2. Fitness calculus routine

IV. CASE STUDY

We have tested the proposed simulation environment setup for the design of rectifiers with near sinusoidal input currents (RNSIC), proposed and thoroughly analyzed in [9]-[11].

The circuit of the variant with AC – capacitors is depicted in Fig. 3.

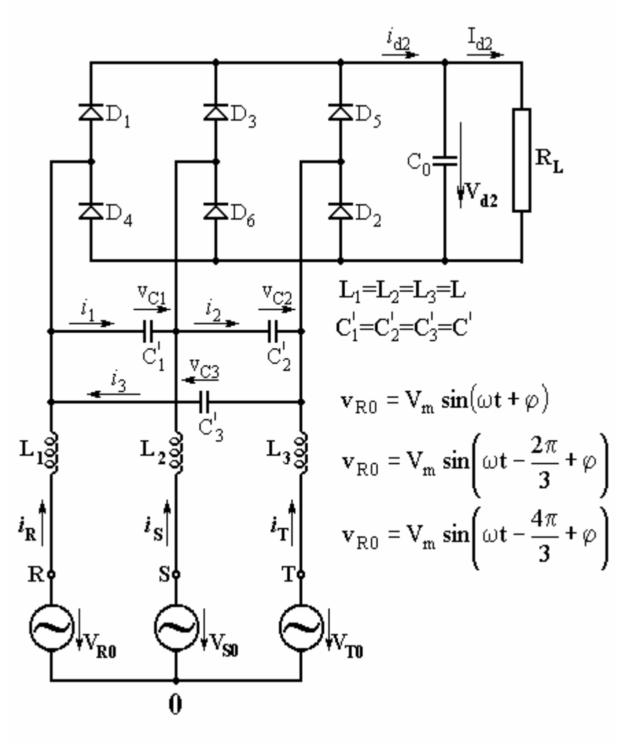

Fig.3. RNSIC converter with capacitors on the AC side

Several simulation techniques have been used to verify the design. We have extensively exploited different simulation environments such as Saber, [12], or MATLAB, [13]. Basically, we have explored extensively the search domain and evaluate the converter behavior, choosing then the best solution.

It though proved that it would be extremely interesting to have the possibility of optimizing the design taking into account different non-electrical aspects, as for example costs or size. For example, in order to increase the ratio between the maximum and minimum fundamental line current, the parameter $\omega^2 LC'$ should be small, for smaller THD the parameter should be as large as possible, but still satisfying the condition:

$$0.05 \le LC'\omega^2 \le 0.10 \quad (1)$$

while for smaller costs, the parameter should be smaller.

Literature has reported several noteworthy results in using GA aided design of power systems which allowed approaches similar to our purpose, [4], and, even much more, indicating significant improvements of the design as compared with classical approaches, [1],[2]. This is the reason of adopting the GA - based simulation environment described in the previous section as a tool for the design of RNSIC converters.

We have adopted a binary encoded decimal representation of the genomes, as suggested in [7] and have used, for the beginning, the standard simple genetic algorithm, described by Goldberg, [5]. This algorithm uses non-overlapping populations and elitism. For each generation, an entirely new population is created by selecting individuals for mating from the previous population, according to a specified selection method.

To test the simulation setup we have devised a simple objective function for evaluating the THD factor. In order to perform the transient analysis of the converter, having in view the time constants of the system, one can estimate that the steady – state is reached in less that 4 seconds. The .out file generated by the PSPICE simulation is processed and the THD is extracted and returned by the objective function.

The experiments we have conducted focused for the beginning in minimizing the only the THD factor for a given rated load.

After several runnings we have chosen the a population of 10 individuals, the probability of crossover of 0.6 and the probability of mutation of 0.01. The phenotype map was defined to represent the float values with 24 bits, in a prescribed range of values for capacitance and inductance respectively. The ending criterion was set to be the evolution over 10 generations.

For the particular set of simulation parameters, the execution on a Pentium II running at 400 MHz was less than 20 min.

In Table 1 we give comparative results of RNSIC performances for two sets of $\omega^2 LC'$ parameter, namely 0.0782 (L = 18mH, C = 44uF), value obtained previously using classical design and 0.089420 (L = 28mH, C = 32uF) value obtained using GA-aided design. V_{d2} represents the output voltage, $I_{(1)}$ – the fundamental of the line current, φ - the phase displacement angle between the phase voltage and the fundamental of the phase current, THD is the total harmonic distortion and the ratio $I_{(5)}/ I_{(1)}$ specifies the relative magnitude of the most important current harmonic, namely the fifth.

It is to be noticed that together with the reduction of the THD a smaller displacement angle φ has been obtained.

TABLE 1

COMPARISON BETWEEN CLASICAL AND GA-BASED DESIGN OF RNSIC-2 CONVERTER

K1 = LC ω^2 = 0.0782 (L = 18 mH, C = 44 uF) K_2 = LC ω^2 =0.089420 (L = 28 mH, C = 32 uF)

R_L [Ω]	V_{d2} [V]		$I_{(1)}$ [A]		φ [°]		THD [%]		$I_{(5)}/ I_{(1)}$ [%]	
	K_1	K_2	K_1	K_2	K_1	K_2	K_1	K_2	K_1	K_2
20	611	532	40.7	33.24	+10.2	+22.0	3.92	3.15	3.7	3.0
40	661	660	27.2	24.1	-30.4	+11.7	3.92	3.5	3.8	3.4
60	676	686	22.9	19.61	-45.3	-29.7	3.91	3.43	3.7	3.3
80	671	697	21.2	17.52	-54.8	-41.4	3.68	3.36	3.57	3.2
100	677	703	20.2	16.43	-61.0	-49.5	3.72	3.33	3.6	3.2
150	678	707	19.0	15.17	-69.9	-61.67	3.39	3.22	3.26	3.1
200	675	708	18.4	14.53	-74.4	-68.15	3.01	3.0	2.86	2.3

IV. CONCLUSIONS

A complex simulation setup for the design of power converters was proposed. The environment is built around a GA engine and includes the PSPICE kernel for the circuit analysis. The main benefit of the proposed approach is that it provides the user the possibility to include various design specifications, including non electrical ones, such as costs, size etc and also to perform complex application specific signal processing .

A case study to illustrate the efficiency of the setup was presented and the results obtained so far are encouraging, especially taking into account the fact that the execution time proved not to be prohibitive.

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