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RESONANT CIRCUIT DESIGN USING ADAPTIVE GENETIC ALGORITHM

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ABSTRACT

The present work explores tuning of inductor and capacitor parameters for series and parallel circuits for resonance. A set of inductor and capacitor values can satisfy the condition of resonance in the series circuit and anti-resonance in the parallel circuit, but our problem is to find the values of these parameters within the feasible range and with minimum size. The bigger size inductors and capacitors may not be feasible or may be very cumbersome and uneconomical to fabricate and install, so we need to find out optimized inductor and capacitor parameter values within feasible range. GAs for the present application is coded in MATLAB.

Keywords: Genetic Algorithm, MATLAB.

1. INTRODUCTION

The Genetic Algorithms (GA) are based on mechanism of evolution of species on earth and mimics the principle of natural selection and population genetics. The basic concept of Genetic Algorithms was first proposed by J.H. Holland in 1950s (J.H. Holland 1975)(John H Holland n.d.).Genetic Algorithms starts with representations for possible solutions in an appropriate form, which are called chromosomes. The chromosomes as in case of living beings, consists of a series of genes which may be represented by real or binary codes. Each chromosome represents one possible solution to the problem under consideration. The whole set of chromosomes is termed as population or one generation. Chromosomes undergo evolution in every generation and biased towards evolution of better solution of the problem at hand. Three basic GA operators reproduction, crossover, and mutation are tools of evolution. The reproduction, operates on a population and reproduces copies of chromosomes with partial genetic materials from the participating chromosomes and the newly created chromosomes are called offsprings. In The crossover operator randomly selects two chromosomes and joins subsections of the two chromosomes to produce the offspring. Mutation is a rare phenomenon, therefore the probability of mutation is very low. Randomly selected genes in chromosomes are altered by a probability equal to the specified mutation rate. In case of binary coding of gene, the digit 1 becomes digit 0 and vice versa. The fitness function or objective function evaluates the chromosomes and calculates the fitness of all chromosomes in a generation. Fitness is a measure of goodness of a chromosome towards providing solution to the problem under consideration. The iteration process continues and average fitness in every evolution iteration increases. A stopping criterion is designed to stop the evolution process and best chromosomes are reported as solution to the problem under consideration. One symbolic conceptual procedure of Genetic Algorithms evolution from one generation to the next is shown in Figure 1. The whole population is evaluated by the Objective/fitness function. The selection operator works on the Darvinian principle. The three basic Genetic Algorithms operators, i.e., reproduction, crossover, and mutation are implimented.

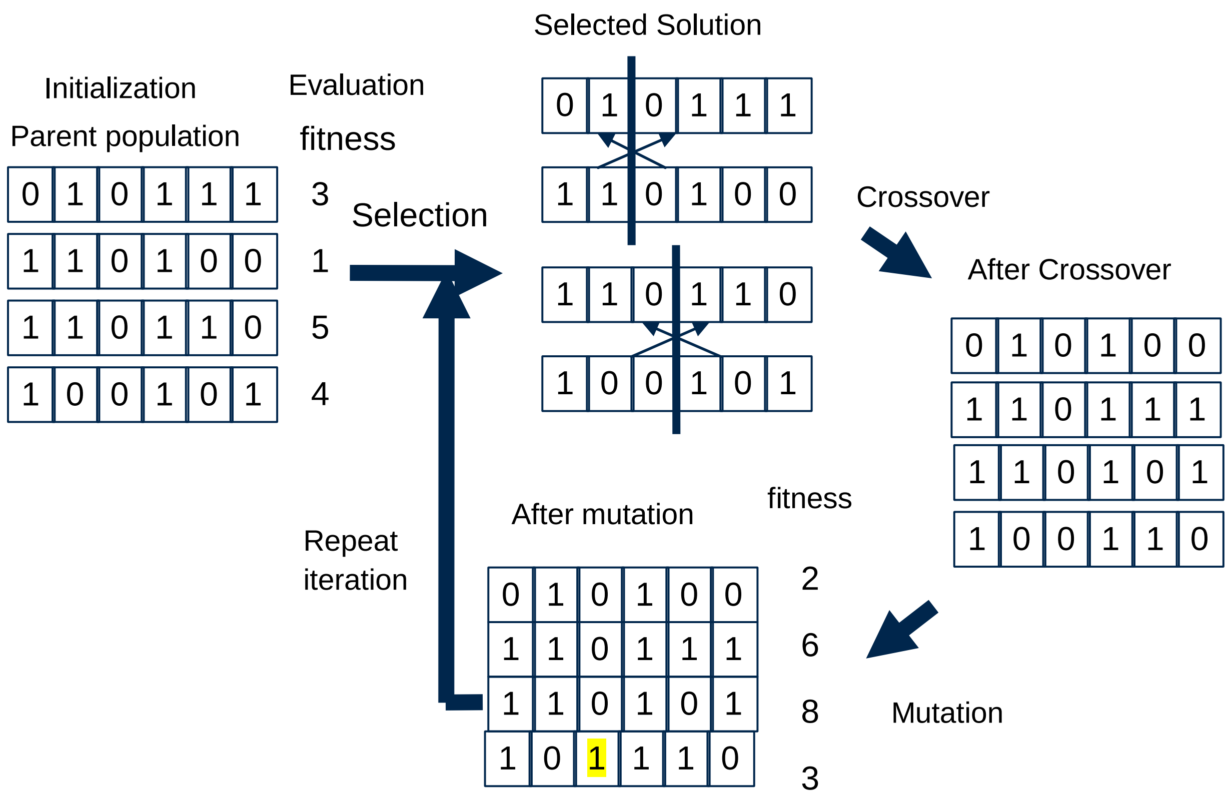

Figure 1: Symbolic scheme of a binary coded Genetic Algorithm

Genetic Algorithms suitable computational tools for complex optimization problems(Goldberg 1989). GA do not use derivatives. GAs are parallel search algorithms. This paper presents application of Genetic Algorithms for tuning inductor and capacitor parameters for series and parallel circuits for resonance.. Mathematical equations do exist for different configurations of series and parallel circuits that can directly work out the resonance frequency for given values of inductance and capacitance. However, the reverse problems of tuning inductor and capacitor parameters for a particular frequency for resonance of a series LCR circuit and anti resonance for a parallel LCR circuit are optimization problems which can be aptly solved using Genetic Algorithms.

2. HISTORICAL PRESPECTIVES

The roots of evolutionary computations lies in 1950s(Aronszajn 1950). The field of evolutionary computation remained less known to scientific community for around three decades, due to the lack of powerful computing platforms at that time, &also due to methodological limitations of early propositions(Fogel 1962). The work of Holland (John H Holland n.d.), (Yao, Liu, and Lin 1999),Fogel (Fogel, 1962) Schewefel (M. Tomassini, 1995) reported during the 1970s. Genetic Algorithms proposed by Holland in the 1950s (John H Holland n.d.) and subsequently progressed by the work of by De-Jong (John H Holland n.d.), Koza (M. Tomassini, 1995), Goldberg(Goldberg 1989), Davis(Lee and Takagi n.d.) to name only a few. Evolutionary computation have found applications in the domain of optimization . The classical or canonical Genetic Algorithms were typified by fixed-length binary representation of individuals, & fixed domain-independent operators.

Natural selection, crossover & mutation are the basic concepts with natural evolution providing foundations for genetic algorithms. The evolutionary process of the Genetic Algorithms takes place on chromosomes, which are the biological edifices, that contains encoded genetic material, which determines the structure of living beings. In Genetic Algorithms, chromosomes are the typically encoded binary strings with allele values of zero or one at each bit position (loci). Natural selection is the process by which chromosomes having more fit encoding have greater probability of reproducing than those having weaker encoding. Once selected for reproduction, chromosomes

exchange genetic material by the cross over of alleles from one chromosome to another creating quite different offsprings. Mutation introduces variability by altering chromosomes making them different from their parents.
Evolutionary Algorithms have been applied to Circuit design and other applications in Electronics and Electrical engineering and a brief overview of research work carried out in the field of interest is presented here. Passive filters are designed for rectifier applications. The survey presents a review of circuit design applications of Evolutionary Algorithms. Alpaydinet.al.(Alpaydın, Balkır, and Dündar 2003) apply an evolutionary approach to the automatic synthesis of high performance analog integrated circuits while Koza (Koza et al. 1997)carry out an automated synthesis of analog electrical circuits by means of genetic programming. A novel tree representation & Genetic programming is used for the analysis of RLC (i.e., resistor, inductor, and capacitor) circuits in(UNNO 2007), Genetic programming (GP) based on the tree representation is also applied to passive filter synthesis problems. The GP is optimized and then incorporated into an algorithm which can automatically find parsimonious solutions without predetermining the number of the required circuit components(UNNO 2007).

3. PROBLEM FORMULATION

In order to make Genetic Algorithms to optimize inductor and capacitor parameters for resonance of a series LCR circuit and anti resonance for a parallel LCR circuit, first the Objective function for the Genetic Algorithm Is to be designed. The following section describes the Objective function for the Genetic Algorithm for the problem at hand and subsequently the Genetic Algorithm is coded using Matlab and the simulation results are presented.

3.1 Objective Function for the Genetic Algorithm

A major task for a Genetic-Algorithms-based solution designer is to frame a proper fitness function for the problem at hand. It serves as a fuel for the evolution of the Genetic Algorithm. For the chosen application, the choice of fitness functions turns out to be none other than the current through the circuit (in case of series resonance) and the impedance of the circuit (in case of parallel resonance) along with the proper bounds as discussed in the sequel.

A two terminal network consisting of resistive (R) and reactive (Inductance, L, and capacitance, C) components offers a complex impedance. If a time varying voltage is applied to such a network, the current is not in phase with the applied voltage. However, under special circumstances, impedance offered by the network becomes purely resistive and the applied voltage and current in the circuit come in phase, this phenomenon is called resonance. The frequency at which it happens is called the resonant frequency. This frequency is unique for a given combination of circuit parameters (L and C) but is independent of the resistive element (R). However, the reverse is not true, i.e., for a given frequency, there exist several values (in fact, infinite) of L and C that can produce resonance condition. This spurred us to apply the Genetic Algorithm approach to this problem, where GA could also take care of practical considerations such as bounds and penalizing non feasible values during the evolutionary process.

The resonance may be classified into two groups Series resonance and parallel resonance or Anti resonance

3.1.1 Series resonance

A time varying voltage (V) sends a current (I) through the circuit. The impedance, Z, of circuit (Figure 2) is:

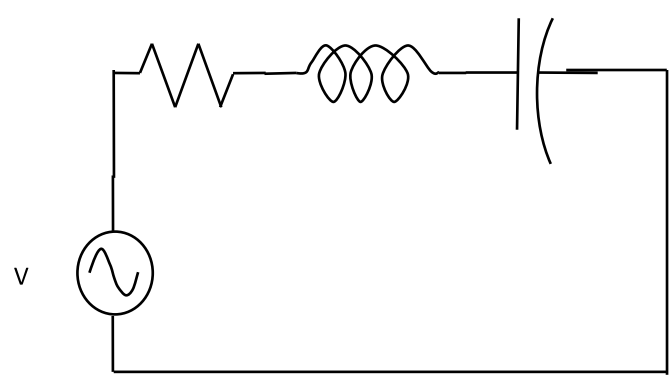

Figure 2: RLC Series Circuit for Simulation

$$Z = R + j(\omega L - 1/\omega C) \quad (1)$$

$$|Z| = \text{sqrt}\,[R^2+(\omega L - 1/\omega C)^2] \quad (2)$$

$$\Rightarrow I = V/[R + j(\omega L - 1/\omega C)] \quad (3)$$

$$|I| = V/\text{sqrt}\,[R^2 + (\omega L - 1/\omega C)^2] \quad (4)$$

The series resonance condition is characterized by purely resistive impedance which, in other words, means that the choice of frequency (f) or the choice of L and / or C is such that the resultant reactance of the circuit is zero. This frequency is called as the resonant frequency of the network. As seen from (2), this impedance shall be minimum. Accordingly, from (4), the current in the circuit under resonant condition will be maximum. Thus, to detect the resonance condition, 'I' can be maximized. Hence, for the series circuit, 'I' as such can be used as a part of fitness function for the Genetic Algorithm. Following is the pseudo code for objective function for this part of simulation:

```
Begin
        Fetch Population
        Evaluate Chromosome values
        For I = 1 : 1 : population size
                Evaluate Current values for each chromosome
                Check chromosome values for feasibility
                (i.e. bounds C <= 10mF & L <= 1000mH)
                Store a pair of L & C if satisfying resonance condition and bounds.
        End.
        Search min value set of L & C from combinations fulfilling resonance condition.
        Store fitness values for the population.
End.
```

3.1.2 Parallel Resonance or Anti resonance

A parallel Resonant or Anti-resonant circuit (Figure 3) consists of an inductance L in parallel with a capacitor C. The capacitor and inductor are assumed to be pure, and a resistance (R_L) is connected in series to inductor, and resistance R_C is connected in series to capacitor C. At parallel resonance or Anti resonance, the impedance becomes highest and the current is minimum in the circuit.
The impendence of circuit is:

$$Z= [(R_L+ j\omega L).(R_C +1/j\omega C)] /[R_L+ j\omega L+ R_C +1/j\omega C] \quad (5)$$

After simplification we get

$$Z=[(R_L-R_C\omega^2LC)+j\omega(L+CR_LR_C)]/[(1-\omega^2LC)+jwC(R_L+R_C)] \quad (6)$$

$$|Z|=\text{sqrt}[\{(R_L-R_C\omega^2LC)^2+\omega^2(L+CR_LR_C)^2\}/\{(1-\omega^2LC)^2+(wC(R_L+R_C))^2\}] \quad (7)$$

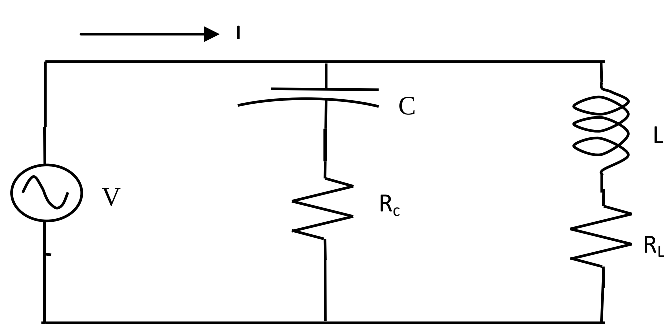

Figure 3: RLC Parallel Circuit for Simulation

This impedance expression is used as part of objective function for Genetic Algorithm, and it is maximized for anti resonance. Fitness functions are not unique for a particular optimization problem and we may design a fitness functions in number of ways, In present case we may find minima of current, as the impedance is maximum, so current is minimum at anti resonance, The Inverse of Current may be used but if during the run of the Genetic Algorithm by default the denominator (Current value) becomes zero than a divide by zero error disrupts the execution of Genetic Algorithm.Following is the pseudo code for objective function for this part of simulation:

```
Begin
        Fetch Population
        Evaluate Chromosome values
        For I = 1 : 1 : population size
                Evaluate impedance values for each chromosome
                Check chromosome values for feasibility
                (i.e. bounds C <= 10mF & L <= 1000mH)
                Store pair of L & C if satisfying resonance condition and bounds.
        End.
        Search min value set of L & C from combinations fulfilling resonance condition in an array to be
        maintained through the evolution process.
        Store fitness values for the population.
End.
```

4. RESULTS & DISCUSSIONS

The Genetic Algorithm developed in matlab run for several times and results tested by plotting graphs from the optimum parameter (L & C) given by the Genetic Algorithm for the circuits designed. Which shows the results are consistent and gives the desired resonant frequency. The results for a sample run are given here:

4.1 Sample run for anti resonant frequency:

The Genetic Algorithm Programme prompts for the two inputs, namely the value of frequency at which the circuit is desired to show anti resonance and the resistance in series of inductor. The outputs are optimized values for Inductor and capacitor to be used for the desired anti resonant circuit and Quality factor (QF) for the evolved circuit, the output GA runs gives the number of iterations the Genetic Algorithm completed before giving the optimized solution. The result of a sample run of the Genetic Algorithm for evolving circuit parameter values for anti resonant circuit is given below:

enter anti resonant frequency = 454

input the resistance in series of inductor for anti resonance(IN OHMS) = 5
GA runs =122

QF =60.4868

inductor_value= 105.8 (mH)

capacitor_value= 1.1562 (uF)

The evolved capacitor and inductor value from Genetic Algorithm are Used and Impedance verses frequency plot is drawn for the resulting circuit (given in Figure 4).

4.2 sample run for resonant frequency:

The Genetic Algorithm prompts for the two inputs, namely the value of frequency at which the circuit is desired to show resonance and the resistance in series circuit. The outputs are, evolved and optimized values for Inductor and capacitor to be used for the desired resonant circuit and Quality factor (QF) for the evolved circuit, the output GA runs gives the number of iterations the Genetic Algorithm completed before giving the optimized solution. The result of a sample run of the Genetic Algorithm for evolving circuit parameter values for resonant circuit is given below enter resonant frequency 332

input the resistance in series of inductor for resonance(IN OHMS) 5
GA runs =52

QF = 3.7425

inductor_value= 14.6 (mH)

capacitor_value = 15.687 (uF)

The capacitor and inductor values evolved from Genetic Algorithm are Used and current verses frequency plot is drawn for the resulting circuit (given in Figure 4).

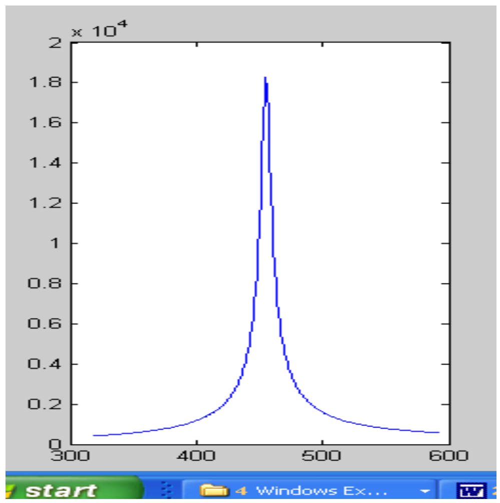

Figure 4: Frequency on x-axis & impedance on Y- axis for Anti-resonant circuit Evolved by Genetic Algorithms .

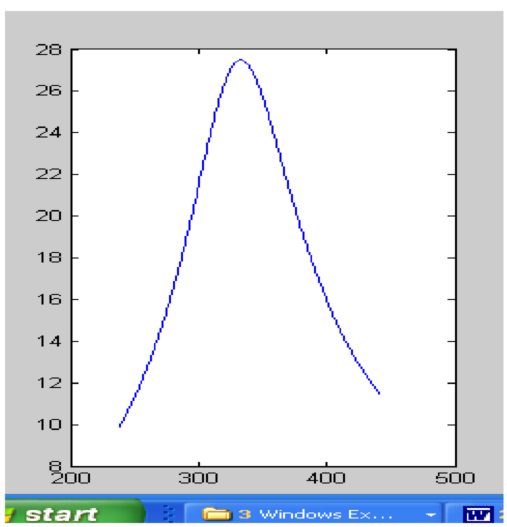

Figure 5: Frequency on x-axis & Current on Y- axis for Resonant Circuit Evolved by Genetic Algorithms.

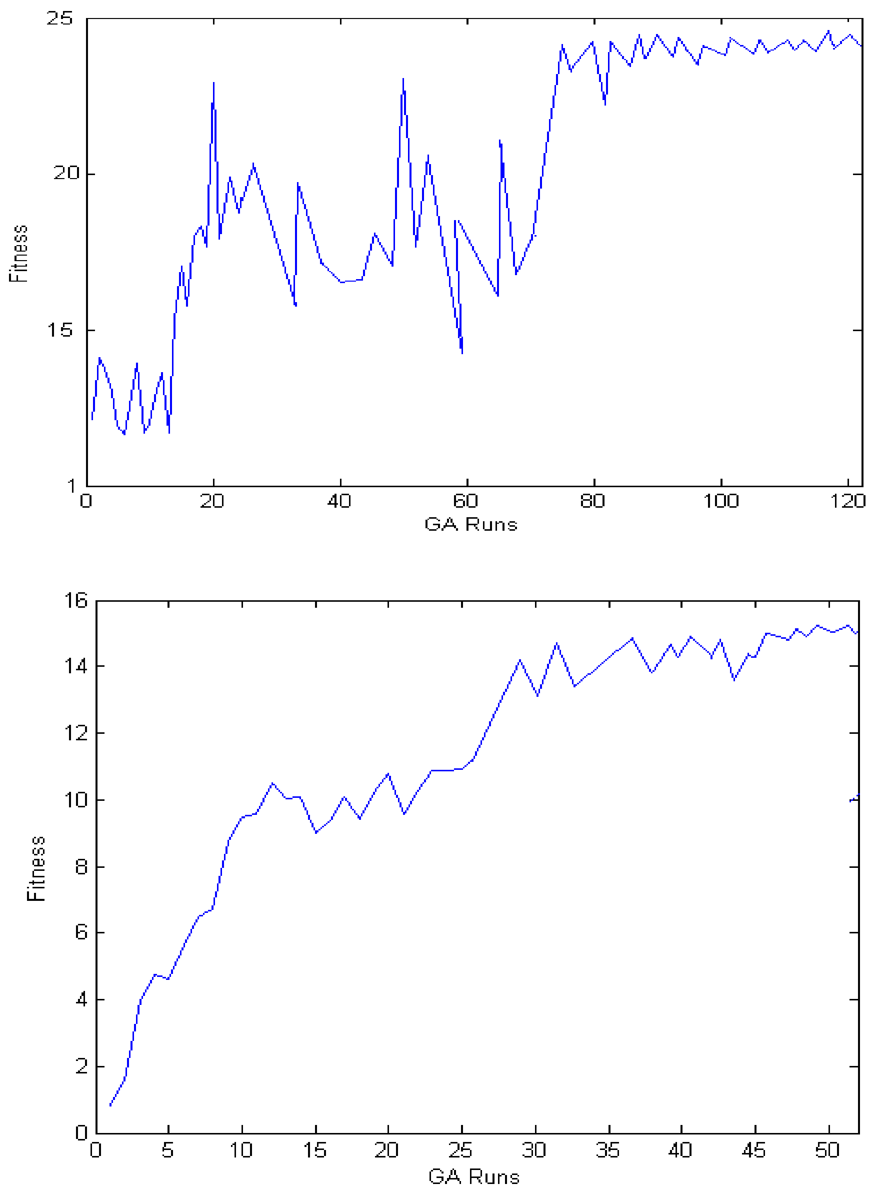

Figure 6: Convergence graph for Genetic Algorithms for (a) Series Resonance (b) Parallel Resonance

5. CONCLUSION

Genetic Algorithm with binary coding has been coded in MATLAB to optimize the inductor and capacitor values of series and parallel resonating circuits Computing frequency of resonance for given values of inductor and capacitor parameters can be accomplished by existing mathematical equations. Finding optimized values of inductor and capacitor parameters from many sets satisfying the condition of resonance is accomplished by Genetic Algorithms. Frequency vs impedance curve for resonating circuit is drawn and resonant frequency is calculated from the GA optimized parameter values for verification of GA optimized results. Frequency vs current curve for anti-resonant circuit is drawn and anti-resonant frequency is calculated from the GA optimized parameter values for verification of GA optimized results. The results from GA simulations show satisfactory optimization of the parameter values.

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