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## Load Test of Induction Motors Based on PWM Technique using Genetic Algorithm

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### Abstract

Genetic algorithms(GA) is optimization technique used in the equivalent load test of the induction motors to select the values of the factors(modulation indicators) that effect on the performance properties in terms of the values of the currents and the total loss within the machine. One way to choose these parameters is by trial and error while this paper based on GA method to improve the parameters selection. A model is designed to simulate the loading of the induction motor and obtain its own results by the MATLAB program 2017a. There are different methods used to achieve this task such as PWM inverter with different modulation techniques, Constant Voltage Variable Frequency (CVVF) method, Variable Voltage Constant Frequency (VVCF) method and Variable Voltage Variable Frequency (VVVF) method.

**Index Terms:** Equivalent load, Induction motor, Genetic algorithms, Modulation techniques.

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### 1. Introduction

The squirrel cage induction Motor type is the most common industrial application in which about 50% of the power is consumed. The advantages of this type of engine are simplicity of design, low price and do not require maintenance such as the type of slip rings. Where, they are durable and carry overload for a long time [1, 2]. Load test for induction motors is intended to know the total loss inside the machine as well as determine the high temperature allowed so as not to affect the insulators of the terminals of the machine.

Naturally, when the machine is energized, it dissipates power. The dissipated power is composed of two

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parts, electrical losses and mechanical losses. The electrical losses are the stator copper loss, the rotor copper loss, the core loss and the stray load losses; windage and friction losses are collectively called mechanical loss. The testing of induction machines to determine the temperature rise as well as the power dissipated inside the machines as heat is a matter of interest to both customers and manufacturers. This is important since it affects the insulation materials, the cooling systems and the efficiency of the machine [3, 4].

Load tests for electric motors are of interest to both the customer and the manufacturer to know the performance characteristics of the engine at full load and allowed high temperature [3]. The methods used to load the electric motors are done in a traditional or unconventional way. The direct method of loading is by coupling between the engine and the load. The equivalent technique is done by double frequency based on two sources of feed or one source, the electric inverter. In large-size electric motors, they cannot be tested for a variety of reasons, including lack of suitable load for high capacity machines, Mechanical load coupling cannot be achieved in vertical position, the test cost is high and high temperature of the equipment during load test because it takes 6 to 8 hours [4].

## **2. Related Work**

There are several related work of load tests for electric motors, In artificial loading methods for induction motors using dual frequency there were two methods of implementation either using two separate sources as found in the research [5-8]. The essence of the synthetic load method was to produce a supply voltage containing two frequencies. This way, two magnetic fields were produced, rotating at different speeds. With the machine running with no mechanical shaft coupling, the rotor oscillate around the synchronous speeds and the machine operate concurrently as a motor and a generator. but one of the disadvantages of this method extra DC machine was required to drive the alternator, mechanical coupling was also needed, separate DC supply to feed the field windings of alternator was required and speed controller for the DC machine was required [9]. The second method was to use only one source, a three-phase inverter as found in research [10-13]. It depends on find the value of the frequency modulation coefficients and the amount of modulation by trial and error according to the available induction motor values. One drawback of using inverters was the large harmonic content in the output voltage which can increase the losses and reduce the system efficiency, but this problem can be overcome using filters [10, 11].

Genetic algorithms are one of the methods of improvement used in multiple industrial fields. This technique relies on random search and is used to solve very complex problems in many areas also used especially when the number of variables is large and difficult to access solutions accurately and ideally. The importance of this strategy is that there is no need to produce good solutions at first in the steps to solve the problem [14]. The purpose of using the algorithms in the process synthetic load of the induction motors is to obtain parameters values for the varies cases "modulation index" for frequency modulation ( $\beta$ ), amplitude modulation ( $\mu$ ) and mixed modulation ( $\beta$ ) and ( $\mu$ ). There are different modulation techniques that can be used with PWM such as: Constant Voltage Variable Frequency (CVVF), Variable Voltage Constant Frequency (VVCF), Variable Voltage Variable Frequency (VVVF).

The main target of this paper is to use of genetic algorithms in the process of artificial loading of inductive motors. In this way the parameters of ( $\beta$ ) and ( $\mu$ ) are determined by the evaluation function, which links the genetic algorithms and the loading of the electric motor. This method was applied with the three different cases of artificial loading and the results were better in terms of the value of total losses resulting from the motor.

The organization of this paper: Genetic algorithms with equivalent loading of induction motors are presented in Section 3. Synthetic load methods using PWM inverter presented in Section 4. Simulation results and discussion for synthetic load using genetic algorithm presented in Section 5, followed by the concluding remarks in Section 6.

### 3. Genetic Algorithms for Synthetic Loading

Genetic algorithm GA is one of the optimization methods that inspired from the natural genetics. Genetic algorithm is a directed random search technique that is widely applied in optimization problems. This is especially useful for complex optimization problems where the number of parameters is large and the analytical global solutions are difficult to obtain [14-15].

The importance of this strategy is to eliminate the problem of local search for solutions because the basis of its work is based on global research for the existence of the best solution and the most appropriate and the most appropriate solution to solve problems. Components of the basic improvement of this technique selection, cross over and mutation respectively [15].

Block diagram representing the GAs routine in Fig. 1, the first step is to generate the initial population, and then to evaluate the fitness value using fitness or objective function. The next step is to perform competitive selection and apply the genetic operators in order to generate new solutions. Finally, evaluate the solutions into the population and start again the procedure from the performance of competitive selection and repeat until some convergence criteria are satisfied.[16-18]

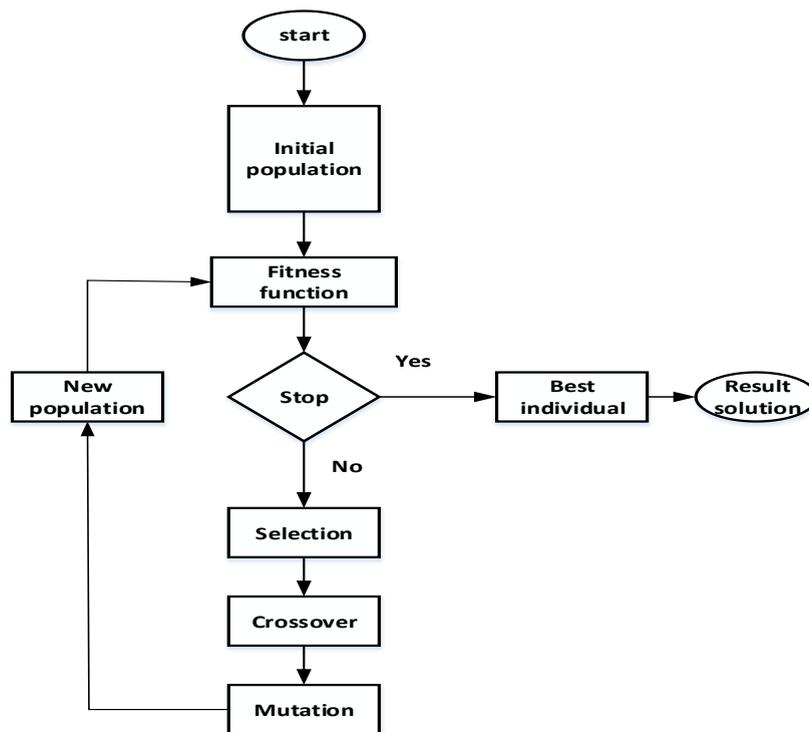


Fig.1. Layout Representing the GAs Routine

The use of genetic algorithms is explained with the induction motor to improve its performance. The purpose of using the algorithms in the process synthetic load of the induction motors is to obtain transaction values for the varies cases "modulation index" for frequency modulation( $\beta$ ), amplitude modulation( $\mu$ ) and mixed modulation( $\beta$ ) and ( $\mu$ ).Initially, the parameters name is changed to make it easier to use it to become as follows:

In the first case of frequency modulation based on two variables  $k_f$  and  $k_s$  where:  $k_f$  is frequency modulation,  $k_s$  is depth modulation. In the second case amplitude modulation based on two variables  $k_f$  and  $k_m$  where:  $k_f$  is frequency modulation,  $k_m$  is depth modulation. In the third case mixed modulation based on three variables  $k_f, k_s$  and  $k_m$  where:  $k_f$  is frequency modulation,  $k_s$  is depth modulation of frequency modulation and  $k_m$  is depth modulation of amplitude modulation.

Integral Square-Error Fitness function (ISE), this type of fitness function is used for genetic algorithms because it is the best species in its performance to achieve synthetic load of induction motor Integral [19].

#### 4. Synthetic Loading of IM using PWM Inverter

In this method, a single source with the rated frequency can be used to generate the mixed frequency supply with the required voltage and frequency values using rectifier inverter set as shown in Fig.2. There are three different modulation techniques to achieve artificial loading using power inverters: Constant Voltage Variable Frequency (CVVF), Variable Voltage Constant Frequency (VVCF), and Variable Voltage Variable Frequency (VVVF).

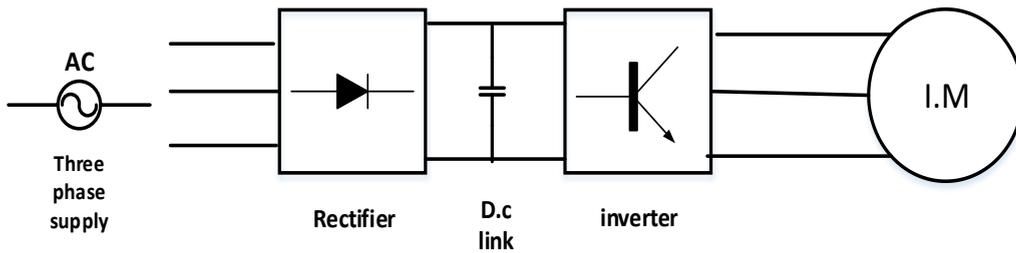


Fig.2. Mixed Frequency using PWM Inverter

##### 1.1. Constant Voltage Variable Frequency (CVVF):

In this case unconventional modes of loading the motor, the electric motor is fed by a PWM inverter where the applied voltage value is constant while the frequency changes with the modulation depth and modulation frequency around the known frequency value of 50 Hz. The change in frequency at a small frequency around the rated frequency causes the machine to operate in a two-direction generator and motor. The power electronic components are used as a three phase inverter because it is very suitable in the electric motor test process. The stator phase voltage is [20]:

$$v(t) = v_a \cos\{[2\pi f_a + \beta \sin(2\pi f_b t)]t\} \quad (1)$$

Where:

- $V_a$ : Amplitude of supply voltage,
- $f_a$ : Supply frequency,
- $\beta$ : Modulation index for frequency modulation,
- $f_b$ : Frequency modulation,
- t: time in sec.

### 1.2. Variable Voltage Constant Frequency (VVCF):

The second case equivalent loading methods of induction motors is known as amplitude modulation or variable voltage with fixed frequency, in this way the voltage is variable and the frequency is constant. This is because in the wave amplitude modulation process depends on the change in the amplitude of the value while the constant frequency which determines this amplitude is modulation index " $\mu$ " for amplitude modulation. The stator phase voltage is [20].

$$v(t) = v_a\{[1 + \mu \cos(2\pi f_b t)] \cos(2\pi f_a t)\} \quad (2)$$

Where,

$\mu$ : Modulation index  $0 < \mu < 1$ ,  
 $f_b$ : Frequency modulation in Hz,  
 $f_a$ = supply frequency in Hz.

### 1.3. Variable Voltage Variable Frequency method (VVVF)

The third case equivalent loading method of induction motors is known as a mixed modulation or variable voltage variable frequency i. e., simultaneous amplitude and frequency modulation (MM), in this way, Voltage and frequency variable values through modulation index of two signals (AM, FM). In this case, the voltage and frequency are changed, but at a constant rate, which depends on  $\frac{\Delta v}{\Delta f}$  characteristic. The stator phase voltage is [21, 22]:

$$v(t) = v_a[1 + \mu \cos(2\pi f_b t)] * \cos[(2\pi f_a t) + \beta \sin(2\pi f_b t)] \quad (3)$$

Where:

$\mu$ : Modulation index for amplitude,  
 $\beta$ : Frequency modulation.

## 5. Simulation Results

Matlab Simulink is used to achieve the equivalent loading of the induction motors using genetic algorithms optimization technique to select the best values of the parameters that affect their performance. After conducting the genetic algorithms on the induction motor, these results are obtained in terms of the values of the currents, voltage, torque and speed, as well as measuring the total losses within it. In the first case of the application of the genetic algorithms on the induction motors. The effect of the genetic algorithms on the induction machine as in Fig. 3 and it expresses its performance characteristics in terms of values of voltages, currents, speed and torque. Also note that the induction machine acts alternately as generator and motor and the speed oscillates around the speed of synchronization, average value speed very close rated nominal speed of the machine. Stator current form is variation because variation in frequency supply at stator voltage or rapidly modulator centre frequency from  $(f_a + k_s)$  to  $(f_a - k_s)$ . The torque is ( positive-negative ) action this demonstrates the motor –generator with cycles synthetic load since half one cycle torque(positive value)motor action while another half cycle torque ( negative value) generator action.

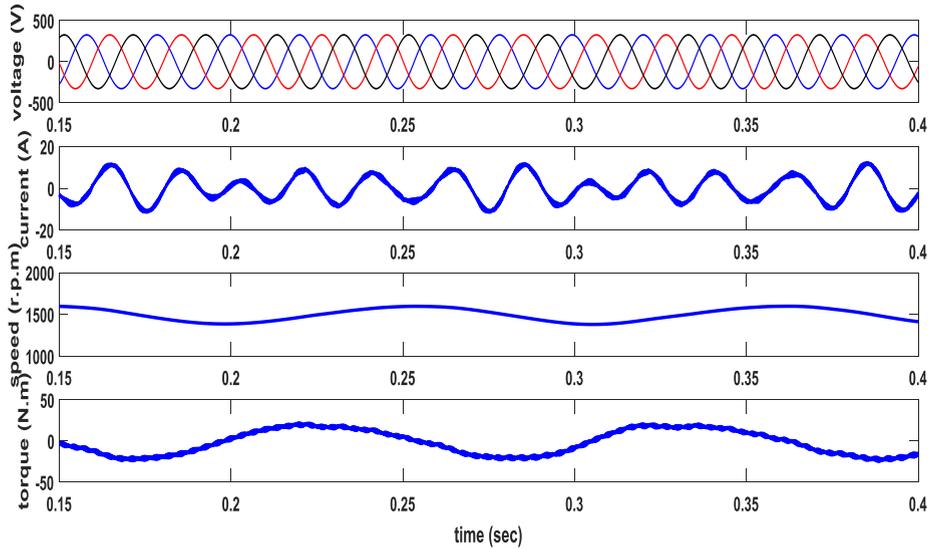


Fig.3. Genetic Algorithms for CVVF

Calculate the instantaneous value of the power through the instantaneous values of current and voltage as the two values are multiplied to obtain the power value. Thus the input instantaneous active power is at times positive or negative. The average power per cycle represents the average total losses in the induction motor per cycle as shown in Fig.4.

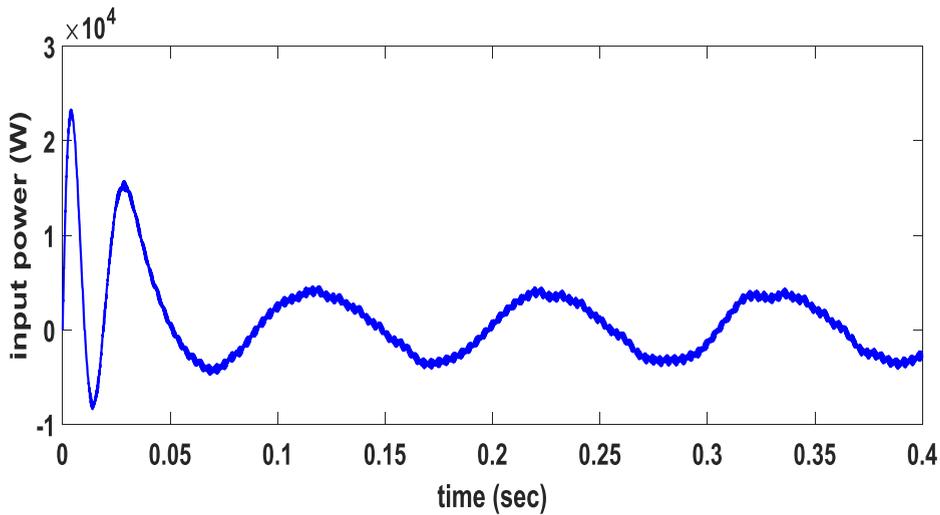


Fig.4. Input Power Value CVVF

The total losses value is 506 W the value of losses in the induction machine by taking the average value of the input power as shown in Fig.5.

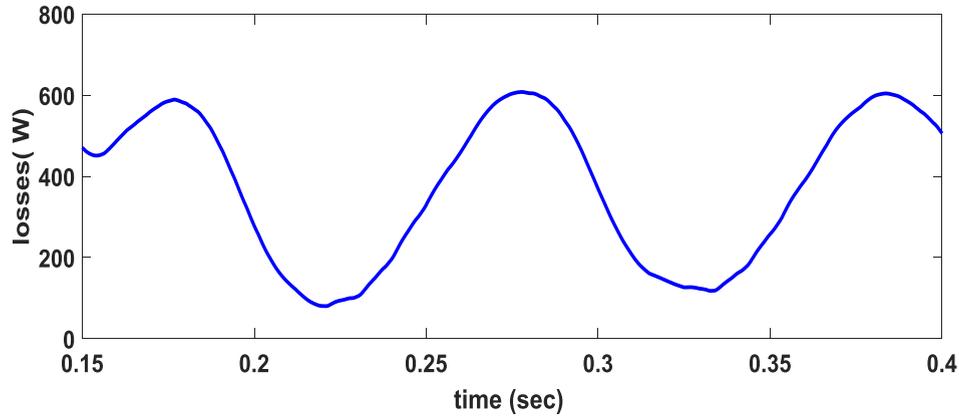


Fig.5. Total Losses Value CVVF

The RMS current value in this case is 5.736 A in Fig.6. These results are taken at the number of attempts at the generation stage at 40 generations for genetic algorithms. In case of frequency modulation, the values of frequency modulation  $k_f = 9.347$  Hz and frequency depth  $k_s = 3$  Hz.

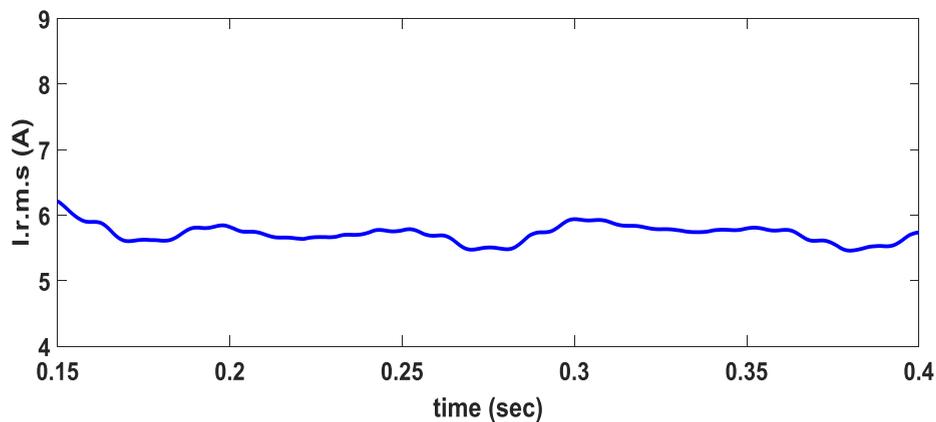


Fig.6. IRMS-value CVVF

In the second case is the amplitude modulation by the genetic algorithms on the induction machine to apply the artificial loading results of its performance of the voltage and current, speed and torque is illustrated in Fig.7 as mentioned above. Initially the voltage is variable in amplitude depended on depth modulation  $k_m$  and the frequency supply is constant. The shape of current here is variable value because it is under influence modulation index for amplitude modulation  $k_m$  and frequency modulation  $k_f$ . The speed of the induction motor during equivalent loading process and we observe the change in value because the machine operates in two cases motor and generator. The torque oscillates between positive and negative values.

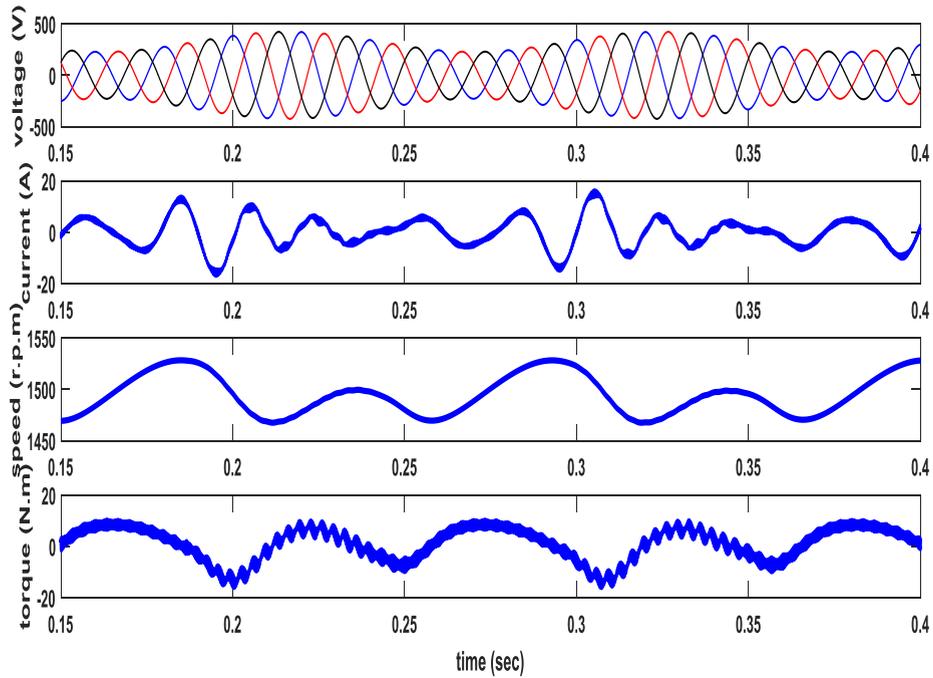


Fig.7. Genetic Algorithms for VVCF.

In this Fig.8 shows the input power, which changes its value resulting from multiplying both phase current and phase voltage.

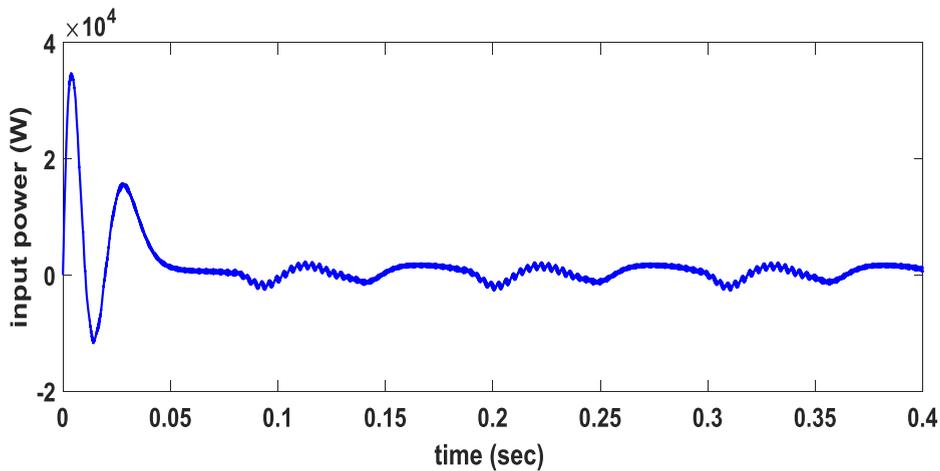


Fig.8. Input Power Value VVCF.

Fig.9 shows Total losses in the method of equivalent loading determined by calculating the mean of the active power value in the second method. The total loss value in this method is about 360.4 W.

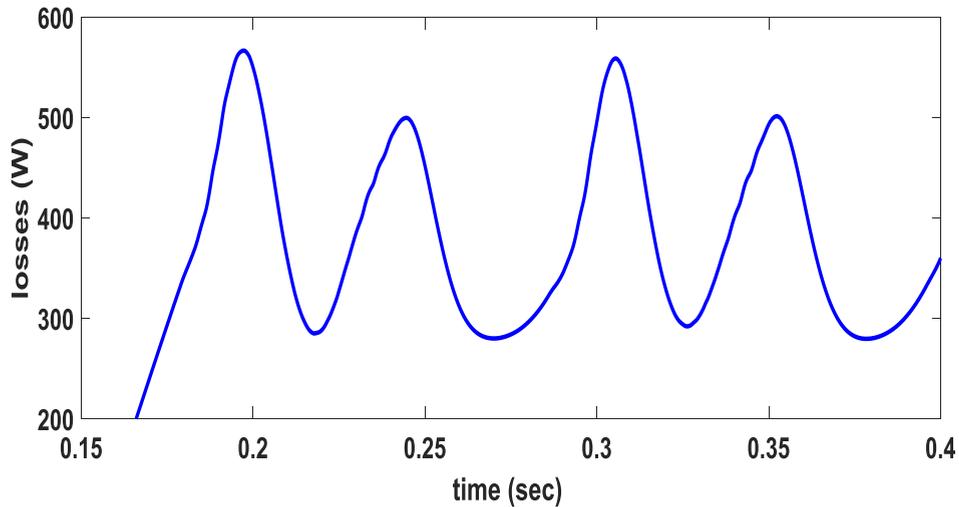


Fig.9. Total Losses Value VVCF

In this Fig.10 the RMS current value in this case is 5.499 A. These results are taken at the number of attempts at the generation stage at 40 generations for genetic algorithms. In case of amplitude modulation, the values of frequency modulation  $k_f = 9.259$  Hz and modulation depth  $k_m = 0.3$  V.

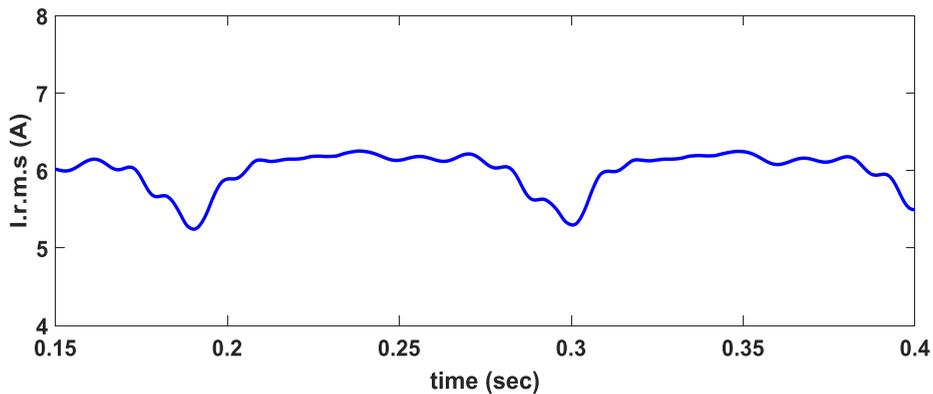


Fig.10. IRMS-value VVCF.

In the third case, the values of both frequency and voltage are changed and therefore are called variable voltage variable frequency. After application of the genetic algorithms with this method the results of the properties of the emissivity of the induction machine as shown in Fig.11. Initially the voltage is variable in amplitude and the frequency of this voltage is variable but the change ratio is constant in the voltage values with the frequency. The shape of the current is oscillating because it is under the influence of application modulation index frequency modulation and amplitude modulation. The speed value is about the speed of the synchronization and the torque is in the working period of the machine as a motor with a positive value while in the operation of the machine as a generator is a negative value.

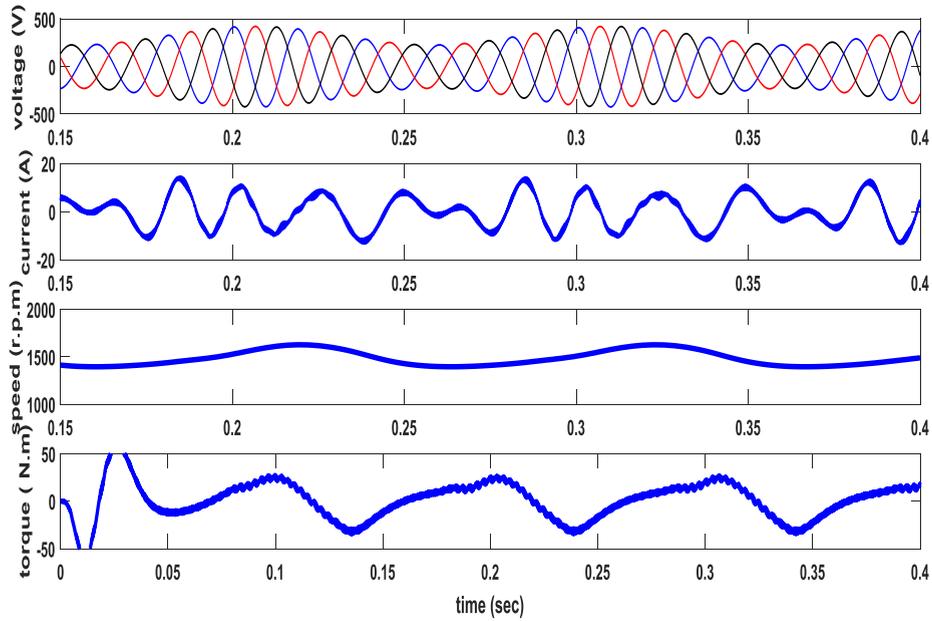


Fig.11. Genetic Algorithms for VVVF.

In this Figs.12, 13 the input power of the electric motor is the multiplying of both the current and voltage values, the value of the total losses through the average value of the input power is about 478.8 W.

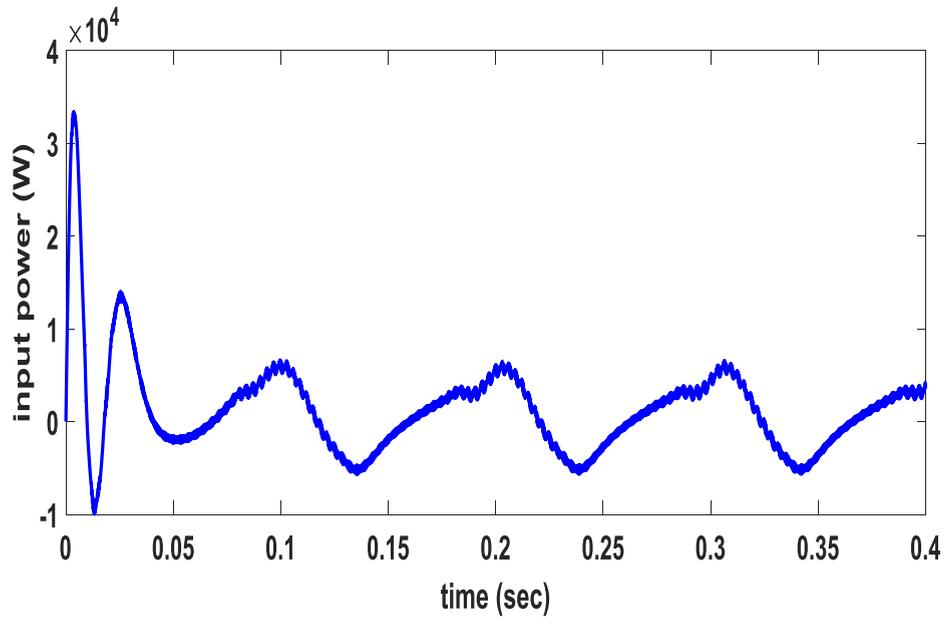


Fig.12. Input Power Value VVVF

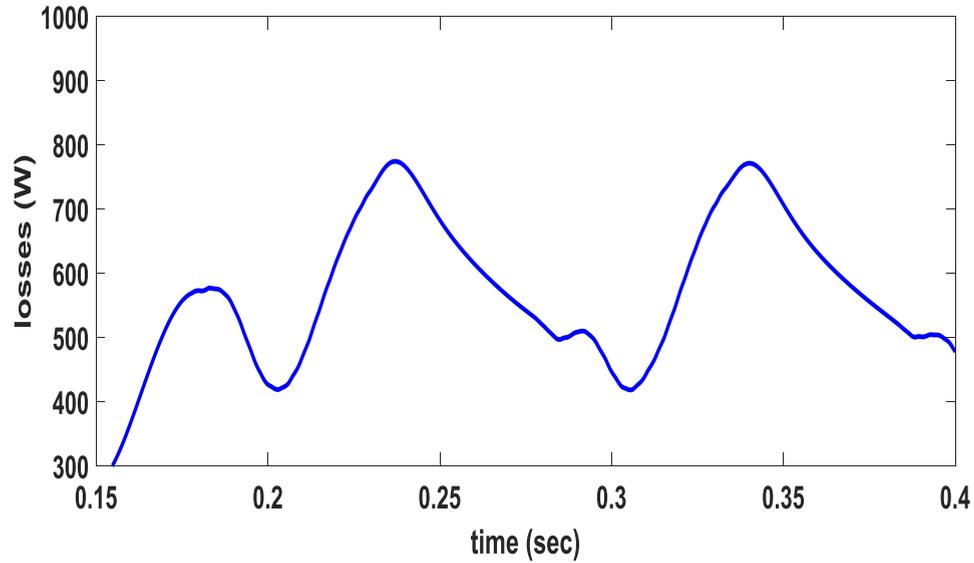


Fig.13. Total Losses Value VVVF.

The RMS current value in this method is 6.661 A as shown in Fig.14. These results are taken at the number of attempts at the generation stage at 40 generations for genetic algorithms. In case of mixed modulation, the values of frequency modulation  $k_f = 9.687$  Hz, frequency depth  $k_s = 3.843$  Hz and modulation depth  $k_m = 0.3$  V. In the Table.3 below, we compare the three methods of artificial loading with the genetic algorithms in which the values of the currents and the total losses within the machine are evaluated.

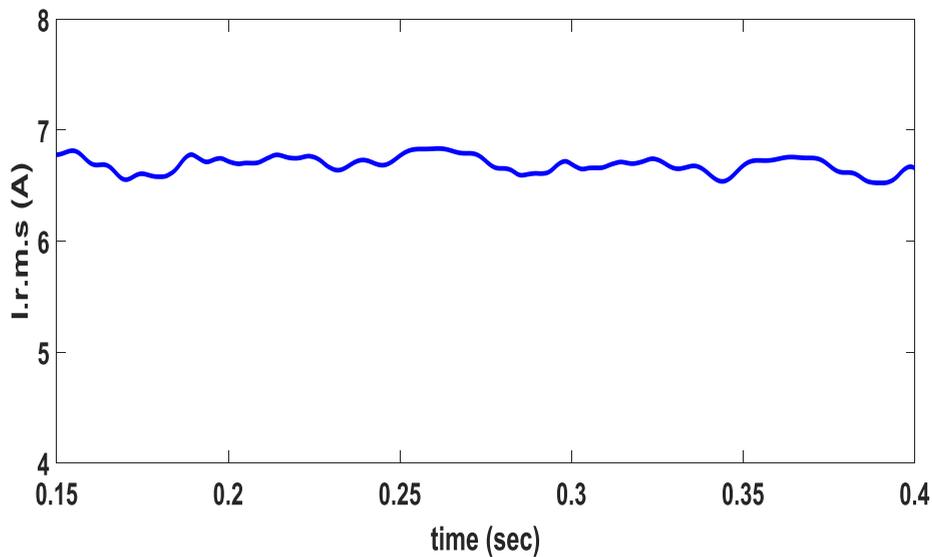


Fig.14. IRMS-value VVVF.

Note that the current value is less than the standard value because the number of attempts in the algorithms is used at 40 generation if higher attempts can produce more accurate results. The losses are also less because they depend mainly on the currents drawn from the machine. It is also confirmed that the machine operates in two cases of alternating operation. Genetic algorithms are chosen as the optimal values for both  $\beta$  and  $\mu$  from basic and very important parameters in the equivalent loading process to be done correctly.

## 6. Conclusion

In this paper, the basis of the work of equivalent loading of induction motors based on PWM-VSI technique was presented. Genetic algorithms were also used to select the values of  $kf$ ,  $ks$  and  $Km$  which affect the loading process to obtain the required currents and the loss of the induction motors. The model simulation and results obtained through Matlab 2017a were performed. The three methods performed on induction motors are CVVF, VVCF, and VVVF. It is important to specify an objective function that links both algorithms with the equivalent load. The higher the number of repetition attempts and the fitness function is selected in a precise way, the better the parameters for the modulation index of the induction motor.

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## Appendix

Three phase induction motor parameters are shown in Table1 and Simulation parameters of genetic algorithms are shown in Table 2.

Table 1. Three phase I.M parameters.

PARAMETER	VALUE
Supply voltage ( $V_s$ )	400 V
Stator resistance( $R_s$ )	1.405 $\Omega$
Rotor resistance ( $R_r$ )	1.395 $\Omega$
Stator leakage inductance ( $L_{ls}$ )	0.005839 H
Stator leakage inductance ( $L_{lr}$ )	0.005839 H
Rated stator current ( $I_s$ )	7.94 A
Rated output power ( $P_o$ )	5.4 HP
No. of Poles (P)	4
Moment of inertia (J)	0.0131Kg.m <sup>2</sup>

Table 2. Genetic Algorithms Parameters.

comparison	CVVF	VVCF	VVVF
Initial population	200	200	200
No. of generation	40	40	40
No. of crossover	0.8	0.8	0.8
No. of mutation	0.01	0.01	0.01
$K_f$	9.347	9.259	9.687
$K_s$	3	-	3.843
$K_m$	-	0.3	0.3

Table 3. RMS Current and Total Losses for three Methods Synthetic Load.

Comparison	$\beta = \frac{KS}{KF}$	$\mu = Km$	RMS current I <sub>rms</sub>	Total losses
CVVF	$KS = 3 \text{ Hz}$ $kf = 9.347 \text{ Hz}$	.....	5.736 A	506 W
VVCF	$kf = 9.259 \text{ Hz}$	$Km = 0.3 \text{ V}$	5.499 A	360.4 W
VVVF	$ks = 3.843 \text{ Hz}$ $kf = 9.687 \text{ Hz}$	$Km = 0.3 \text{ V}$	6.661A	478.8 W

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