Evolution in Electrical and Electronic Engineering Vol. 3 No. 1 (2022) 252-261

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Development of RLC Circuit Modelling for Simulation of Stator Winding Frequency Response using Genetic Algorithm

Nur Ainaa Amirah Che Ku Abu Bakar[1], Mohd Fairouz Mohd Yousof[1]*

[1]Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Johor, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/eeee.2022.03.01.029
Received 20 January 2022; Accepted 24 April 2022; Available online 30 June 2022

Abstract: The induction motor is one of the AC motors commonly used in the industry as it comes with excellent advantages. AC motor can run as a single-phase induction motor (SPIM) or a three-phase induction motor (TPIM). This TPIM motor is the most frequently used in many industries due to its excellent features. However, TPIM can be prone to electrical faults that lead to stator faults. Therefore, the condition assessment of the motors has drawn considerable attention to keep the operation running smoothly. Frequency Response Analysis (FRA) can be used to determine the state of the stator winding. This method was previously only utilized to analyze the frequency response of power transformers. The FRA method is the most effective for detecting motor failure or damage as a reference for evaluating the measured response. An RLC circuit model is developed using MATLAB/Simulink to simulate the frequency response of the stator winding. The response from the RLC circuit model will then be compared with the actual measurement. The Genetic Algorithm (GA) improves the simulated response to get the precise and accurate parameters for each element to minimize the response error.

Keywords: RLC Circuit Modelling, Frequency Response, Genetic Algorithm

1. Introduction

The rapidly evolving industries nowadays have suggested that there will be increasing demand for rotating machines. A motor is a rotating machine that converts tremendous amounts of universal energy into mechanical energy [1]. These motors are primarily designed to be operated whether on alternate current (AC) or direct current (DC). The induction motor and the synchronous motor are two kinds of AC motors. The AC motor can run on a single-phase AC source known as a single-phase induction motor (SPIM) or a three-phase AC source, namely a three-phase induction motor (TPIM) [2]. TPIM has a vital role in industries for driving applications. Almost 70% of motors in industries are TPIM [3]. However, electrical faults such as stator faults usually occur in the TPIM.

**Corresponding author: fairouz@uthm.edu.my*

Frequency response analysis (FRA) is an approved and reliable technique for determining the state of a power transformer [4]. Typically, FRA is used to detect the physical displacement of core and winding faults in the transformer. The frequency response of the induction motor that has not been unmounted will be measured using this technique. The type of fault and its severity can be determined by comparing the FRA of a healthy condition with the faulty condition of the stator winding. An optimization algorithm is a method that compares multiple solutions iteratively until the best or most appropriate one is found. Optimization has become a part of computer-aided design activities since the invention of computers. The design objective of optimizing design could minimize production costs or production efficiency [5].

Thus, the paper proposed a solution for the problem by developing an RLC circuit model to simulate the frequency response of the stator winding of the TPIM. The model's frequency response is improved by using the genetic algorithm (GA). GA is used to get the precise and accurate parameters for each element in the circuit model to minimize the response error [6]. The simulated RLC circuit model's frequency response will then be compared with the initial measurement frequency response.

2. Materials and Methods

2.1 Method

Figure 1 shows the flow chart of the project.

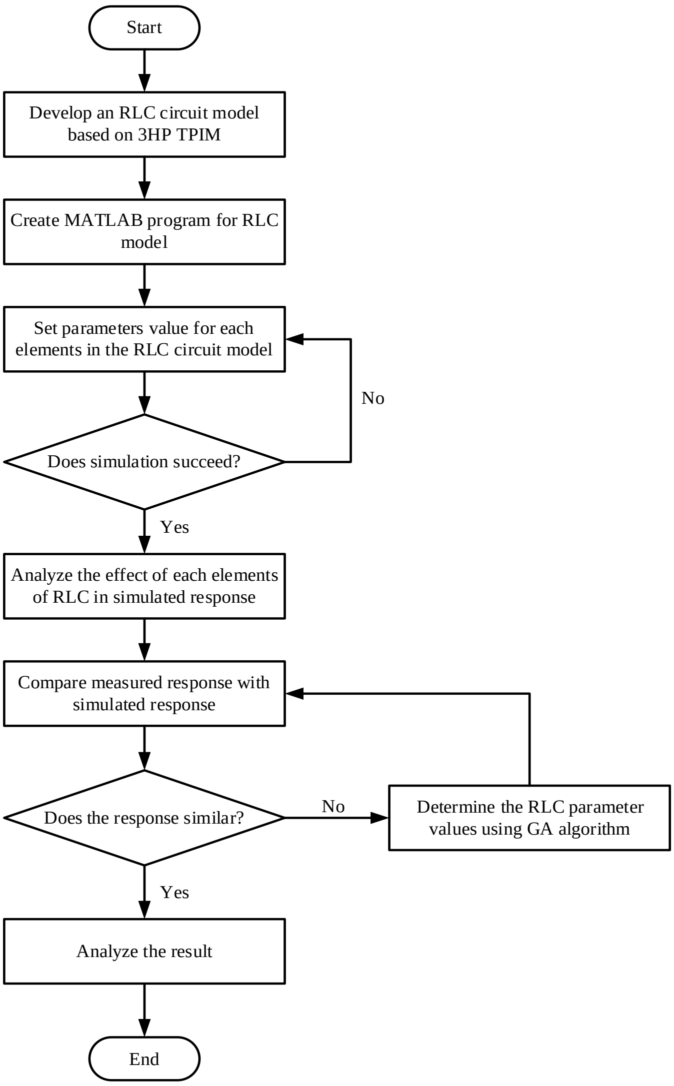

Figure 1: Flowchart of project

Before proceeding to the simulation, the first stage is gathering additional knowledge by reading papers, journals, websites, and theses from previous research to better understand the modelling of a TPIM. Next, develop an RLC circuit model based on the TPIM with a power rating of 3HP using MATLAB/Simulink. After that, create coding for the simulation of the RLC circuit model, which is related to the FRA. The parameters of each element in the RLC circuit model are set in this programming code. Then, run the simulation and compare the simulated response with the initial measured response. As the simulated response is not similar to the measured response, the effect of each parameter in the RLC circuit model is being analyzed. The RLC parameters are determined using the GA algorithm to improve the simulated response.

2.2 Three-Phase Induction Motor

In this study, one unit of TPIM was chosen to conduct this study with a power rating of 3HP. This motor was chosen as it is widely used in the industrial drive due to its rugged construction, low cost, and minimum maintenance. It is designed according to IEC standards with a rated output of 2.2kW/3HP, 2840 rpm rated speed, and a rated voltage of 415V/50Hz. The summary of the specification of the TPIM is shown in Table 1.

Table 1: Specification of TPIM

Specification of TPIM	
Manufacturer	JILANG
Model	Y90L-2
Phases	3-ph induction motor
Power	2.2kW / 3HP
Rated Voltage	415V / 50Hz
RPM	2840 rpm

2.3 FRA Measurement Connection

Figure 2 illustrates the connection of the FRA equipment, motor terminals, and computer used to perform the FRA measurements on the TPIM windings. The measurement approach was dictated by the winding's connection configuration, which is Wye (Y). The FRA response can be evaluated between two-phase terminals (U-V, V-W, and W-U) or between phase to neutral terminals for the connection winding of the Wye configuration (U-N, V-N, and W-N). As the response is evaluated between two-phase terminals, it is assumed that the neutral point (N) is hidden. Between phase endpoints, the FRA responses were determined.

Figure 2: Equipment connection to measure response using FRA for motor winding [7]

2.4 RLC Circuit Simulation

The developed RLC circuit model in this paper is based on the research work presented in [8]. The equivalent circuit between the model and stator windings is expressed regarding phase-to-phase and phase-to-ground complex impedances. Figure 3 shows the RLC circuit model composed of resistors (R), inductors (L), and capacitors (C) connected in series or parallel.

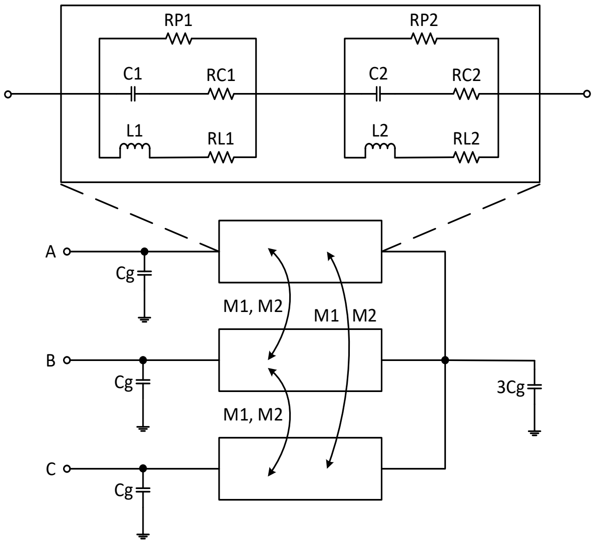

Figure 3: RLC circuit model

The RLC circuit model is redrawn in MATLAB/Simulink. Figure 4 shows the circuit model of TPIM using MATLAB/Simulink. The circuit is the wye connection and consists of three parts of the stator winding. Due to the circuit being in a wye connection, only one part of the stator winding is used to analyse the frequency response. Figure 5 shows the RLC circuit in the stator winding.

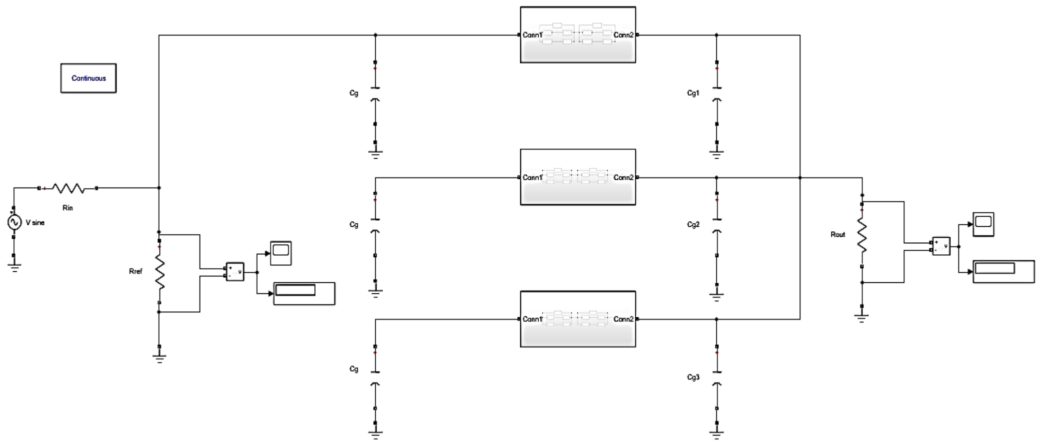

Figure 4: Circuit model of TPIM

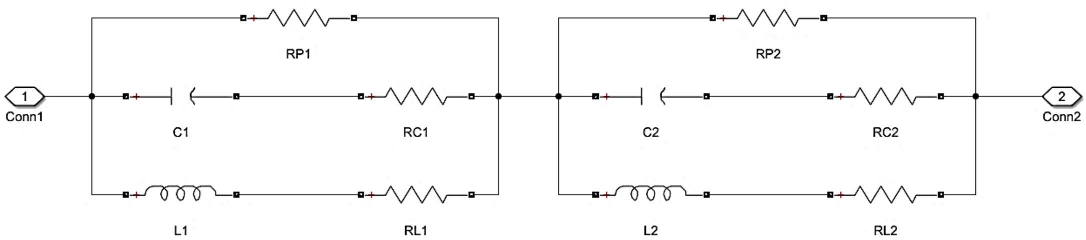

Figure 5: RLC circuit in the stator winding

Table 2 shows the parameter values used in the simulation. All the parameters used are taken from [8] as a reference in this project. The resistance, inductance, and capacitance parameter values may affect the curve of frequency responses. A simple parallel RLC circuit model, as shown in Figure 6, is built to observe the effect of increasing the parameter value of the component in the circuit towards the shape of the frequency response.

Table 2: Parameter values for simulation of RLC model [8]

Specification of Parameter		
C_g	300pF	Phase-to-ground stray capacitance
R_{P1}, R_{P2}	4.8kΩ, 2kΩ	Parallel resistances of the two resonators
C_1, C_2	560pF, 380pF	Stray capacitance of the two resonators
R_{C1}, R_{C2}	10Ω, 15Ω	Series resistance (capacitive branch)
L_1, L_2	3.26mH, 1.15mH	Main inductances of the two resonators
R_{L1}, R_{L2}	100Ω, 80Ω	Series resistance (inductive branch)

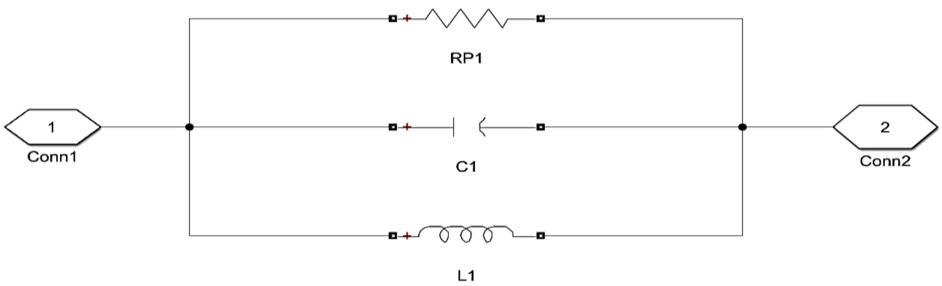

Figure 6: Simple parallel RLC circuit model

3. Results and Discussion

Figure 7 illustrates the comparison between the response curve of the measured and simulated response of the stator winding. It can be observed that there is a massive gap in the response curve in both simulated and measured responses. The simulated response did not have an accurate response curve compared to the actual measurement response. The maximum magnitude is at -20dB in the simulated response, while in the measured response, the maximum magnitude is at -7dB. The minimum magnitude of the simulated and measured response is at -43dB and -53dB, respectively.

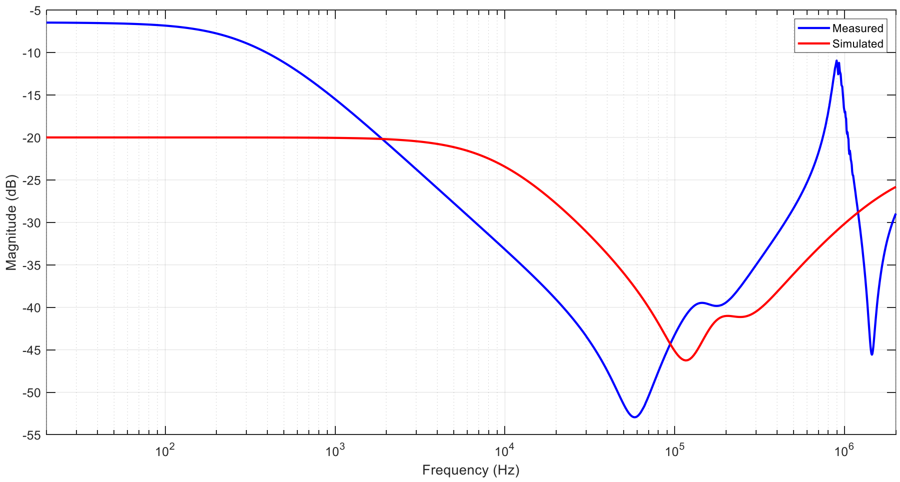

Figure 7: Comparison of the measured and simulated response of stator winding at normal condition

Figure 8 displays the frequency response of the simple parallel RLC circuit model in Figure 6 when the value of RP1 increased by 50% to determine the minimum magnitude of the resonant frequency. By increasing the value of the RP1, the frequency response above 100kHz is affected. The magnitude at the resonance decreases from -46dB to -49dB.

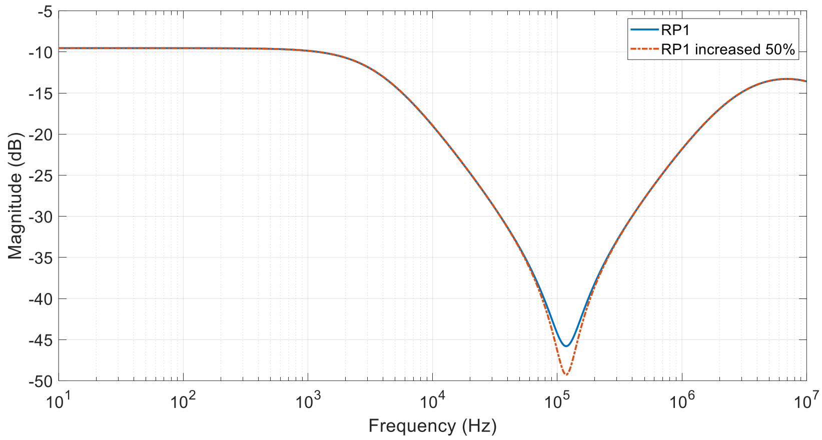

Figure 8: Effect of increasing RP1 value by 50%

Figure 9 shows the frequency response of the simple parallel RLC circuit model in Figure 6 when the value of L1 increased by 50% to observe the frequency response of the positive slope. The positive slope in the response is slightly shifted towards the lower frequency (shift to the left side). As the value of the L1 is increased, the frequency response below 300kHz is affected.

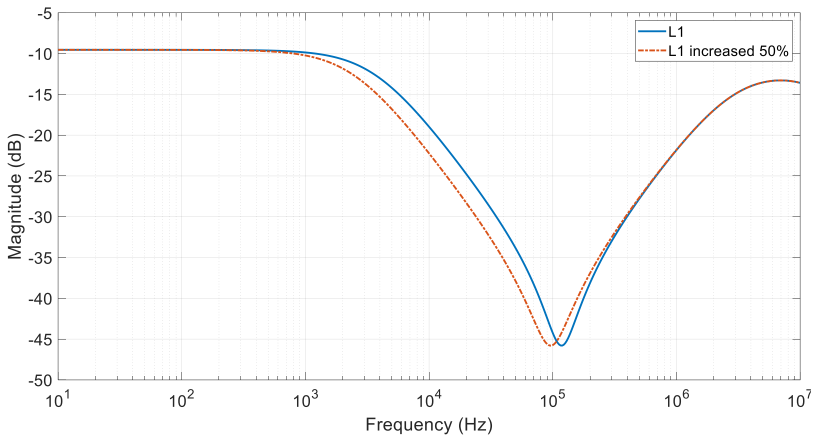

Figure 9: Effect of increasing L1 value by 50%

Figure 10 illustrates the frequency response of the simple parallel RLC circuit model in Figure 6 when the value of C1 increased by 50% to observe the frequency response of the negative slope. The negative slope is slightly shifted towards the lower frequency (shift to the left). The frequency response above 40kHz is affected as the value of C1 is increased.

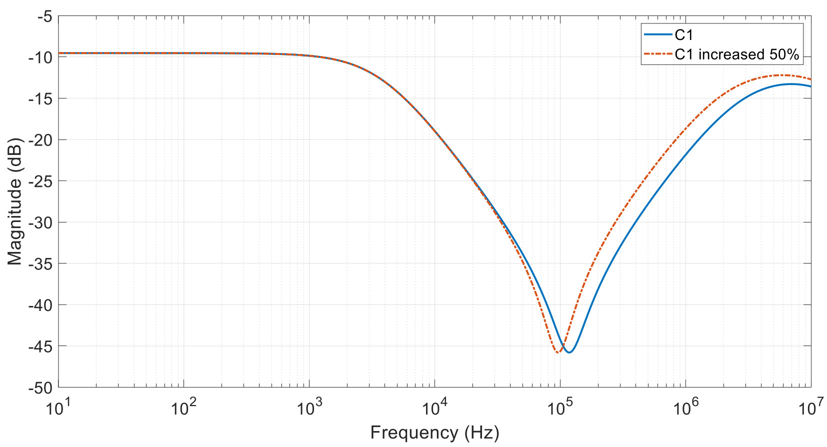

Figure 10: Effect of increasing C1 value by 50%

Figure 11 shows the mean fitness and best fitness for the ten generations of the simple parallel RLC circuit model. Mean fitness refers to the average fitness levels over the entire population, whereas best fitness refers to the fitness of the best individual in the current population. Usually, the mean fitness has the same value as the best fitness. The simulation is run for ten generations with a 100-population size. Table 3 tabulates each generation's best and mean fitness using the GA algorithm. It can be concluded that the value of the best and mean fitness is constant in each generation.

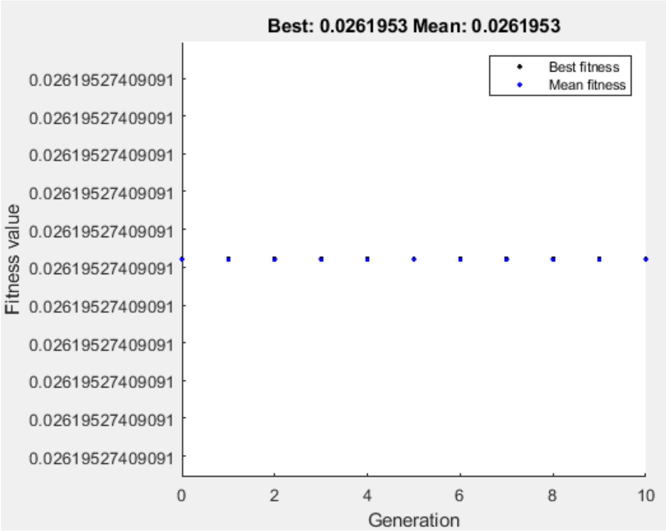

Figure 11: Mean and best fitness of simple RLC circuit model

Table 3: Best and mean fitness in each generation

Generation	Best fitness	Mean fitness
0	0.0261953	0.0261953
1	0.0261953	0.0261953
2	0.0261953	0.0261953
3	0.0261953	0.0261953
4	0.0261953	0.0261953
5	0.0261953	0.0261953
6	0.0261953	0.0261953
7	0.0261953	0.0261953
8	0.0261953	0.0261953
9	0.0261953	0.0261953
10	0.0261953	0.0261953

Figure 12 illustrates the frequency response of the simple RLC circuit using the GA algorithm. The response started to improve at the frequency of 60kHz, and the positive slope is slightly shifted towards the higher frequency (shift to the right).

Figure 13 illustrates the mean and best fitness of the RLC circuit model of TPIM. The simulation is run with 150 generations and population size of 100. Table 4 summarizes each generation's best and mean fitness using the GA algorithm. It can be concluded that the value of the best and mean fitness is constant in each generation.

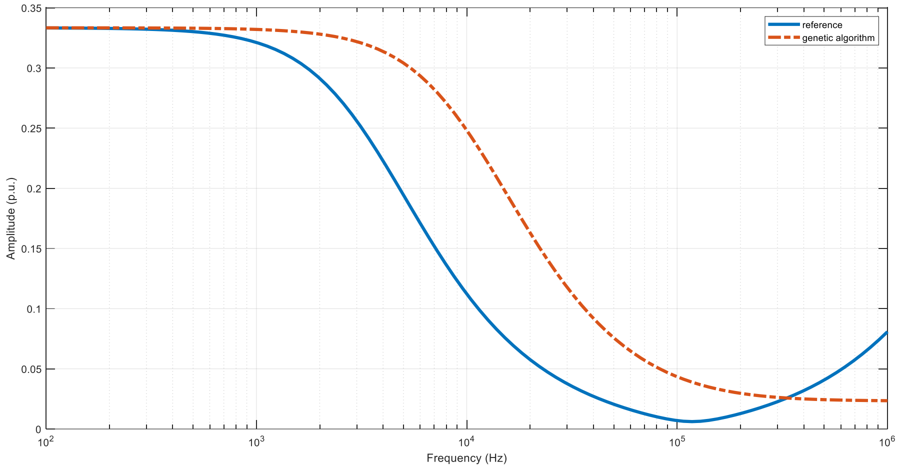

Figure 12: Frequency response of simple RLC circuit model

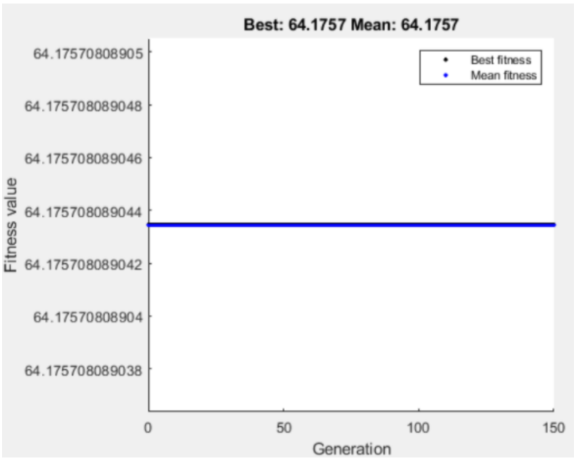

Figure 13: Mean and best fitness of RLC circuit model

Table 4: Best and mean fitness in each generation

Generation	Best fitness	Mean fitness
0	64.1757	64.1757
10	64.1757	64.1757
20	64.1757	64.1757
30	64.1757	64.1757
40	64.1757	64.1757
50	64.1757	64.1757
60	64.1757	64.1757
70	64.1757	64.1757
80	64.1757	64.1757
90	64.1757	64.1757
100	64.1757	64.1757
110	64.1757	64.1757
120	64.1757	64.1757
130	64.1757	64.1757
140	64.1757	64.1757
150	64.1757	64.1757

Figure 14 shows the frequency response of the simulation using GA. For this simulation, the initial response measurement of TPIM is taken as a reference to be compared with the simulated response using GA. The final response cannot be obtained due to some limitations of GA. The algorithm is prone to be stuck at local minima, resulting in the best solution not being found. Other than that, it takes a longer time to run each iteration due to the laptop limitation. The time for each iteration is about three to four minutes which means that the simulation takes approximately eight hours to run for 150 generations.

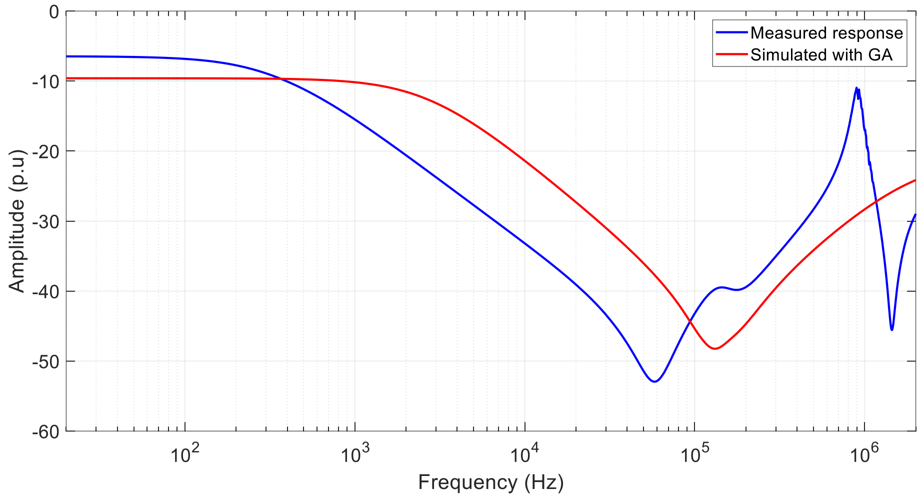

Figure 14: Frequency response using GA algorithm

4. Conclusion

FRA is highlighted as a reliable method for investigating FRA's mechanical state. Findings from this paper;

i. The FRA technique can be used to detect the condition of the TPIM. It is proven by comparing the frequency response of the RLC circuit model, which gives some variation in responses.
ii. The RLC circuit model can act as stator winding to simulate its frequency response. Each component of the RLC has its effect on the frequency response.
iii. The simulation of the RLC circuit using the GA cannot be finalized due to some limitations.

For further research, it is recommended to use a hybrid stochastic optimization technique that can combine two algorithms to complement the weakness of the GA. The hybrid algorithm can save much more computation time than the GA to estimate the parameter values of the RLC circuit model.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

References

[1] A. Dineva *et al.*, "Review of soft computing models in design and control of rotating electrical machines," *Energies*, vol. 12, no. 6, 2019, doi: 10.3390/en12061049.

[2] M. Akar and I. Cankaya, "Broken rotor bar fault detection in inverter-fed squirrel cage induction motors using stator current analysis and fuzzy logic," *Turkish J. Electr. Eng. Comput. Sci.*, vol. 20, no. SUPPL.1, pp. 1077–1089, 2012, doi: 10.3906/elk-1102-1050.

[3] T. G. Vilhekar, M. S. Ballal, and B. S. Umre, "Application of Sweep Frequency Response Analysis for the detection of winding faults in induction motor," *IECON Proc. (Industrial Electron. Conf.*, pp. 1458–1463, 2016, doi: 10.1109/IECON.2016.7793565.

[4] P. Picher, "Mechanical Condition Assessment of Transformer Windings Using Frequency Response Analysis (Fra)," *Evaluation*, no. April, pp. 30–34, 2008.

[5] X. S. Yang, "Optimization and Metaheuristic Algorithms in Engineering," *Metaheuristics Water, Geotech. Transp. Eng.*, no. May, pp. 1–23, 2013, doi: 10.1016/B978-0-12-398296-4.00001-5.

[6] D. E. Golderberg, "Genetic Algorithms in Search, Optimization & Machine Learning," *American Society of Mechanical Engineers, Dynamic Systems and Control Division (Publication) DSC*, vol. 22. pp. 1–25, 1989.

[7] A. A. Alawady, M. F. M. Yousof, N. Azis, and M. A. Talib, "Frequency response analysis technique for induction motor short circuit faults detection," *Int. J. Power Electron. Drive Syst.*, vol. 11, no. 3, pp. 1653–1659, 2020, doi: 10.11591/ijpeds.v11.i3.pp1653-1659.

[8] G. Grandi, D. Casadei, and U. Reggiani, "Common- and differential-mode HF current components in AC motors supplied by voltage source inverters," *IEEE Trans. Power Electron.*, vol. 19, no. 1, pp. 16–24, 2004, doi: 10.1109/TPEL.2003.820564.