Nonlinear Analysis of Nonlinearly Loaded Dipole Antenna in the Frequency Domain Using Fuzzy Inference

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***Abstract*- In this paper, fuzzy inference model is proposed so as to analyze nonlinearly loaded dipole antenna. In modeling process, linear and nonlinear behavior of the problem is saved as simple and unchanged membership functions and the effect of incident wave on the induced voltage at different harmonies are then extracted easily. Consequently the model achieved is more efficient than previous studies such as using neural networks.**

Index Terms- Nonlinear antenna, fuzzy inference, harmonic balance.

I. INTRODUCTION

Nonlinear loads are connected to antennas terminal either to control scattering response or to protect devices against strongly external signals [1-9]. A schematic diagram of nonlinearly loaded dipole antenna as well as individual microwave circuit is shown in Fig. 1. The problem of interest in such application is computing induced voltage across nonlinear load. To this end, several hybrid models have been reported based upon combining the method of moments (MoM) [10] and nonlinear techniques [11] for instance Volterra series [1, 2], and harmonic balance (HB) [3]. MoM is used to compute the antenna parameters such as input admitance and short circuit current, i.e. Y_{in}, I_{sh} at different frequencies, and accordingly HB is used to deal with the induced voltage at different harmonic frequencies. It is well known that such models, suffer from repetitive and complex computation due to analysis of both antenna and nonlinear load. Lee et al [6, 7], used neural networks using radial basis functions (RBF-NN) so as to overcome these drawbacks. Unfortunately in some cases these models firstly need much initial information to create the model and secondly training process is time consuming.

In contrast with the above models, the intelligent model based on fuzzy inference introduced by Tayarani [12] could be used. Recently, this approch has been used by the author in modeling the overhead lines [13]. In this model, the behavior of the problem is represented as linguistic variables or

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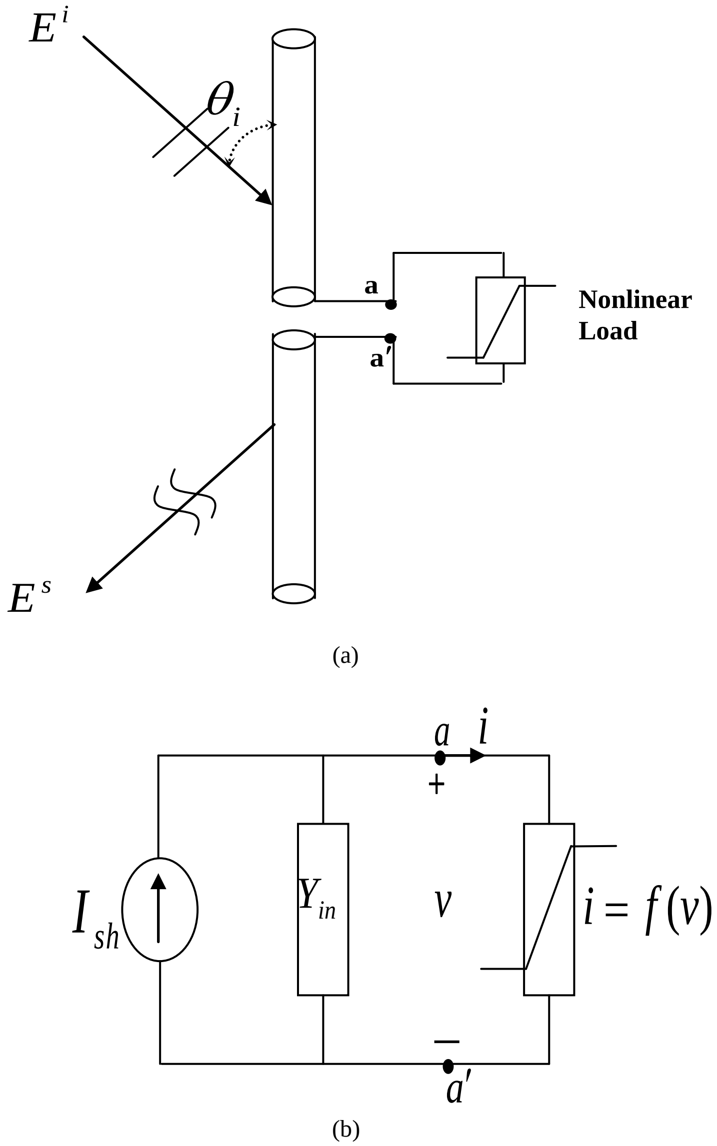


Fig 1. (a): Schematic diagram of nonlinearly loaded dipole antenna, and (b): its nonlinear microwave circuit.

simple membership functions, and the effects of problem parameters on the output as changing center coordinates and radius of basic circles is extracted. Further information about this model is explained in the next section.

In the previous studies by author [14-16], the drawbacks due to antenna analysis (input admittance, induced current and mutual couplings) were completely removed. The remained problem is to deal with the induced voltage efficiently.

It is well known that HB suffers from suitable guess of an initial solution and gradient operations in the iteration procedures and these drawbacks are repeated when the parameters of problem is changed. Note that instead of the HB, the genetic algorithm in [17] can also be used. These motivate the author to overcome these drawbacks using the Tayarani's model [12].

This paper is organized as follows. In section II, the linear behavior of problem is well extracted linguistically, and in following the effect of incident wave on the induced voltage at first harmony is extracted easily. In section III, the nonlinear behavior of problem the same as linear one is saved as membership functions, and the effect of the incident wave on other harmonies is extracted. Finally the conclusion is given in section IV.

II. LINEAR BEHAVIOR OF THE PROBLEM

In this section, consider a dipole antenna of length to diameter ratio 74.2 which is illuminated by a plane wave of magnitude $E_i = 0.1(V/m)$. This antenna is terminated with a nonlinear load having the $(i-v)$ characteristic as following:

$$i = \frac{1}{75}v + 4v^3 \tag{1}$$

To extract linear behavior of the problem, the induced voltage at the fundamental harmony at 111 frequencies in the frequency interval of [0.1-2.3] GHz is computed by HB. Then amplitude versus phase of induced voltage is plotted in polar plane in Fig. 2. In Fig. 2, as L/λ (L is half of dipole length) is increased a circular movement is created. Inside this movement, three circles are distinguishable in such a way that these are converted to each other smoothly. To define these circles, three sets of starting points (stars in Fig. 2) around $L/\lambda = 0.25, 0.75, 1.25$ are first chosen.

The membership functions for expressing circles linguistically are then defined so that they have belongingness one on the fitted circles and smoothly decreasing to zero on the neighbor fitted circles. The general form of this membership functions, is expressed as following:

$$\alpha(L/\lambda) = \begin{cases} \frac{1}{2}(1+\cos\pi(\frac{L/\lambda - a}{b-a})^{\beta_1}) & \text{for} \quad L/\lambda : a \to b \\ \frac{1}{2}(1-\cos\pi(\frac{L/\lambda - a}{b-a})^{\beta_2}) & \text{for} \quad L/\lambda : a \to b \end{cases} \tag{2}$$

Where $\beta_{1,2}$ are optimizing parameters, and a, b are boundary points where the circular movement is separated from the fitted circles. For the problem under consideration, membership functions are shown in Fig. 3.

Now, one can represent the circular movement through the following fuzzy if-then rules.

$$\begin{cases} \text{if} \quad L/\lambda \quad \text{belongs to small set} \to \text{first circle} \\ \text{if} \quad L/\lambda \quad \text{belongs to medium set} \to \text{second circle} \\ \text{if} \quad L/\lambda \quad \text{belongs to long set} \to \text{third circle} \end{cases} \tag{3}$$

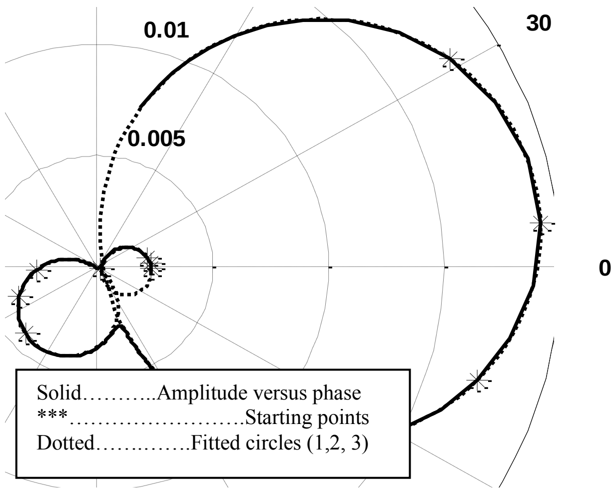


Fig 2. Amplitude versus phase of the induced voltage in polar plane in addition to starting points (stars) for defining fitted circles.

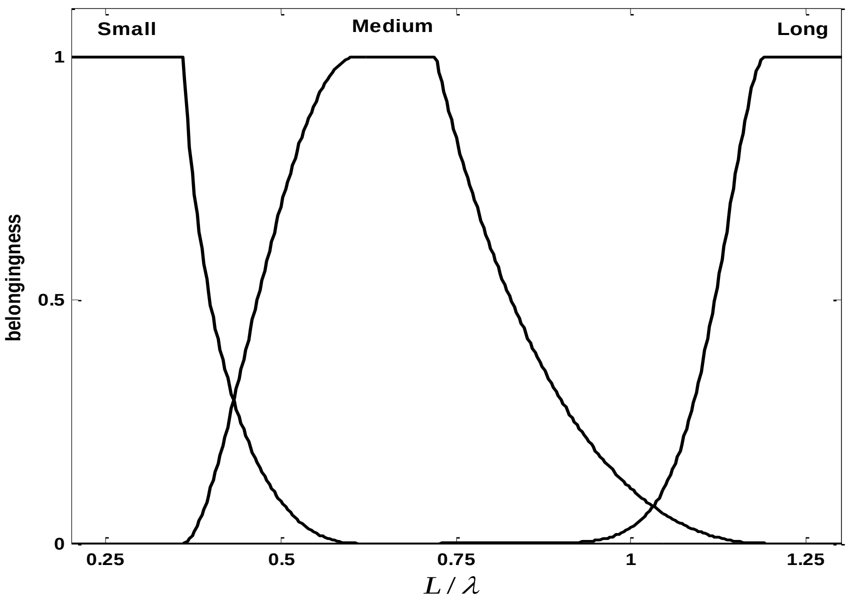


Fig 3. Membership functions for modeling the circular movement.

Using Takagi-Sugeno method [18], the above rules is led to inferring one circle for each L/λ as follows:

$$\begin{cases} x(\frac{L}{\lambda}) = \sum_{i=1}^{3} x_i \alpha_i (\frac{L}{\lambda}) \\ y(\frac{L}{\lambda}) = \sum_{i=1}^{3} y_i \alpha_i (\frac{L}{\lambda}) \\ r(\frac{L}{\lambda}) = \sum_{i=1}^{3} r_i \alpha_i (\frac{L}{\lambda}) \end{cases} \tag{4}$$

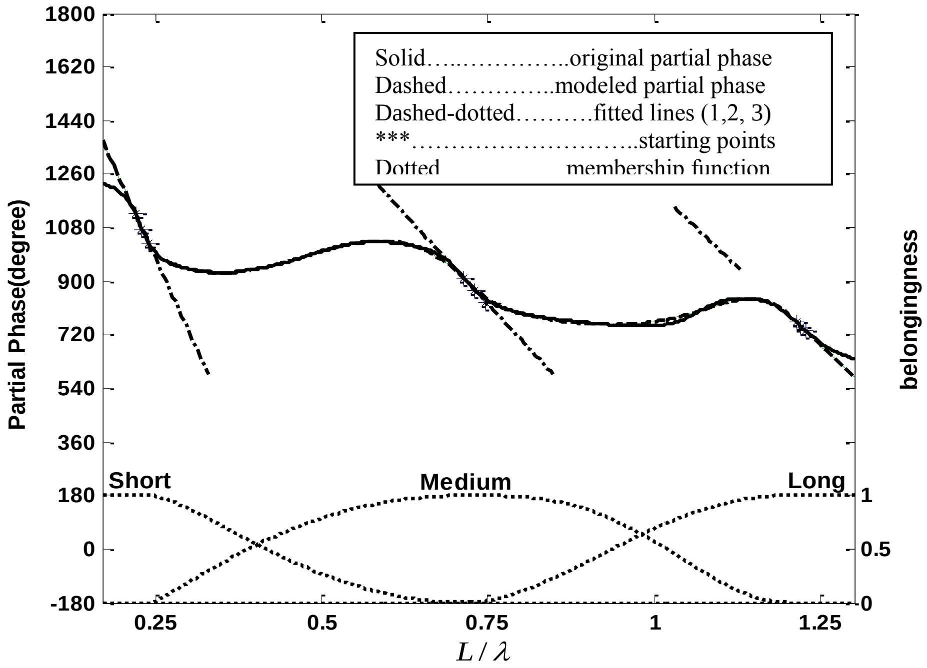


Fig 4. Partial phase, fitted line and membership function for modeling partial phase.

in which $x_i, y_i, r_i, i = 1,2,3$ is center coordinates and radius of the three fitted circles and α_i's are membership functions in Fig. 3. Inferring circles in this step is called partial locus.

According to [12], to find the correct place of the induced voltage on the each inferred circle, the partial phase (phase with respect to the centre of inferred circles) should be defined, and then modeled. The partial phase is shown in Fig. 4.

In Fig. 4, a smoothly decreasing curve as well as three sets of stars is observed. These stars are those used for defining fitted circles and here three lines are fitted on them (dash-dotted lines). Modeling the partial phase is the same as the circular movement except that circles are replaced by lines, i.e., the implications (5) and equation (6) should be used.

$$\begin{cases} \text{if } L/\lambda \text{ belongs to small set} \rightarrow \text{first line} \\ \text{if } L/\lambda \text{ belongs to medium set} \rightarrow \text{second line} \\ \text{if } L/\lambda \text{ belongs to long set} \rightarrow \text{third line} \end{cases} \tag{5}$$

$$\begin{cases} m(\frac{L}{\lambda}) = \dfrac{\sum_{i=1}^{3} m_i \alpha'_i(\frac{L}{\lambda})}{\sum_{i=1}^{3} \alpha'_i(\frac{L}{\lambda})} \\ n(\frac{L}{\lambda}) = \dfrac{\sum_{i=1}^{3} n_i \alpha'_i(\frac{L}{\lambda})}{\sum_{i=1}^{3} \alpha'_i(\frac{L}{\lambda})} \end{cases} \tag{6}$$

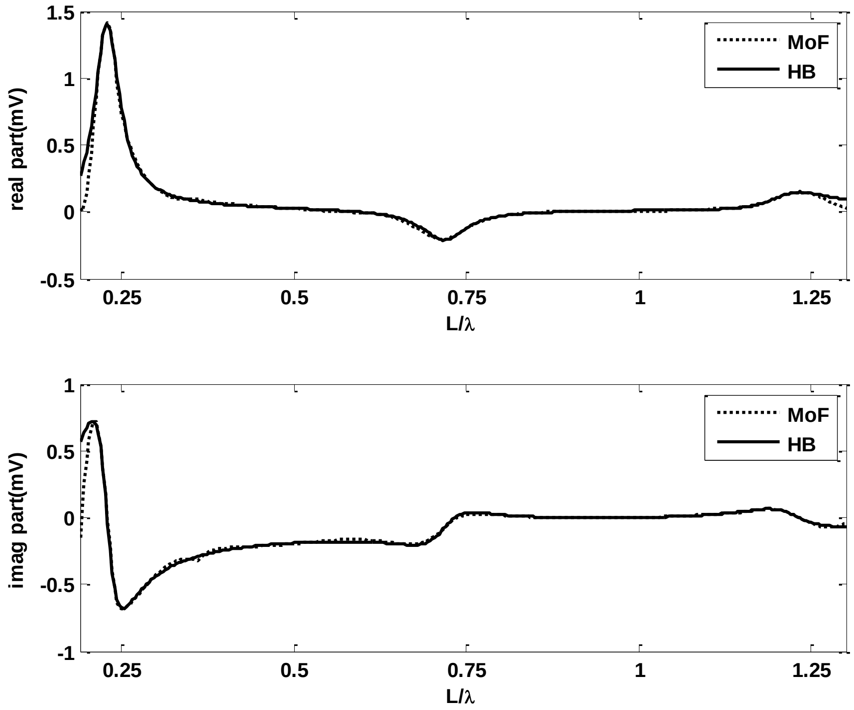


Fig 5. Comparing the induced voltage at the fundamental frequency by the proposed model (MoF) and harmonic balance (HB).

in which $m_i, n_i, i = 1,2,3$ are slope and bias of fitted lines (dash-dotted lines in Fig. 4) and $\alpha_i' s$ are membership functions (dotted curves in Fig. 4). Finally, the real and imaginary part of the induced voltage versus input value L/λ is computed through the below equation:

$$\text{induced voltage}(L/\lambda) = x + jy + r\exp\{j(m \times L/\lambda + n)\} \quad (7)$$

in which, (x, y, r), and (m, n) are computed through equations (4) and (6) respectively, and $j = \sqrt{-1}$.

Fig. 5 shows the predicted induced voltage versus L/λ at the fundamental harmony by the MoF, and HB. As it is seen, excellent agreement is achieved. The membership functions in Figs. 3 and 4 from now on are considered as linear behavior of the problem.

A. Incident wave effect

In the previous section, the magnitude of incident wave was assumed to be constant, and the induced voltage at the fundamental harmony for arbitrary normalized length was predicted. It is well known that, the induced voltage is strongly dependent on the magnitude of incident wave. Hence in this section to complete the model, the effect of incident wave on the first harmony is extracted.

According to [12], changing parameters of problem is just led to changing center coordinates and radius of fitted circles. Hence, center coordinates and radius for a few values of $E_i = 0.1, 0.3, 0.5 (V/m)$ are computed by HB and shown as stars, circles, and squares in Fig. 6.

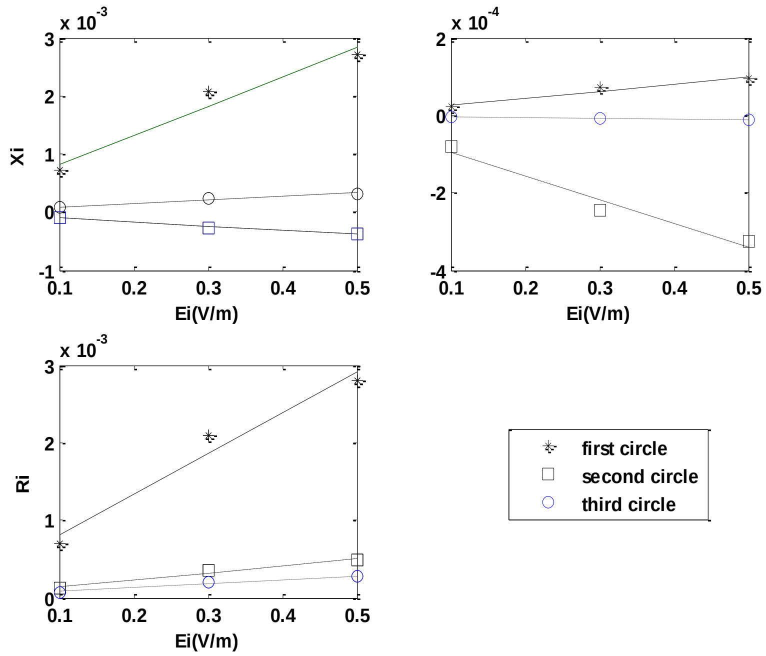


Fig 6. The effect of incident wave on the first harmony of voltage.

As it is seen in Fig. 6, stars, squares, and circles can be fitted by lines. That is, from now on center coordinates and radius for arbitrary magnitude is easily computed through these lines instead of HB. These lines can be considered as effect of the incident wave. To know how accurate the MoF is, sample $E_i = 0.35(V/m)$ is chosen, and then center coordinates and radius of the three fitted circles are computed, and after then using the linear behavior of the problem, the induced voltage at the fundamental harmony for arbitrary L/λ is efficiently computed as shown in Fig. 7.

It is worth comparing the results in this section with the forth example in [5] (see Fig. 6 in [5]). In this study, through the MoF, 111 data for L/λ and 3×9 data for E_i (each sample E_i requires $3\times 3 = 9$ starting points) totally $111 + 3\times 9 = 138$ data is required. Also L is half length of dipole whereas in [5] L is total length. This shows the MoF is so efficient. These advantageous are owing to modeling in polar plane and new definition of phase, i.e., partial phase.

III. NONLINEAR BEHAVIOR OF THE PROBLEM

As reported in [5, Fig. 3], since the second harmony for the chosen nonlinear load in (1) is negligible, thus this harmony is not predicted in this section. Hence the third harmony is investigated.

In the same manner with the fundamental harmony, third harmony can be modeled. Hence, amplitude versus phase of the induced voltage at the third harmony is computed by HB and shown in Fig. (8).

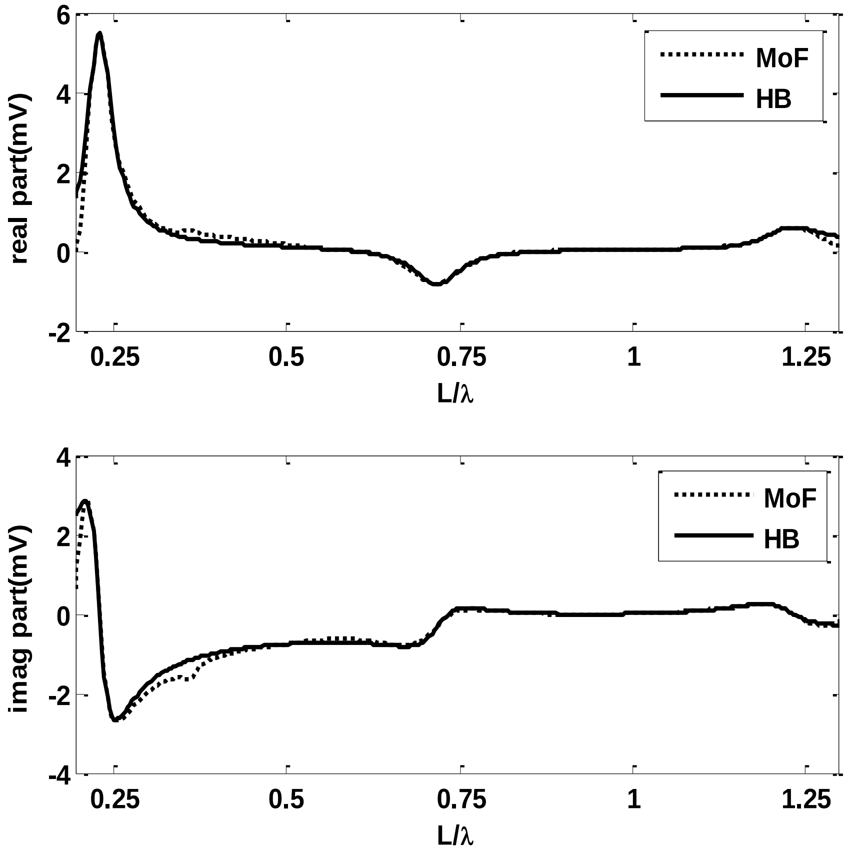
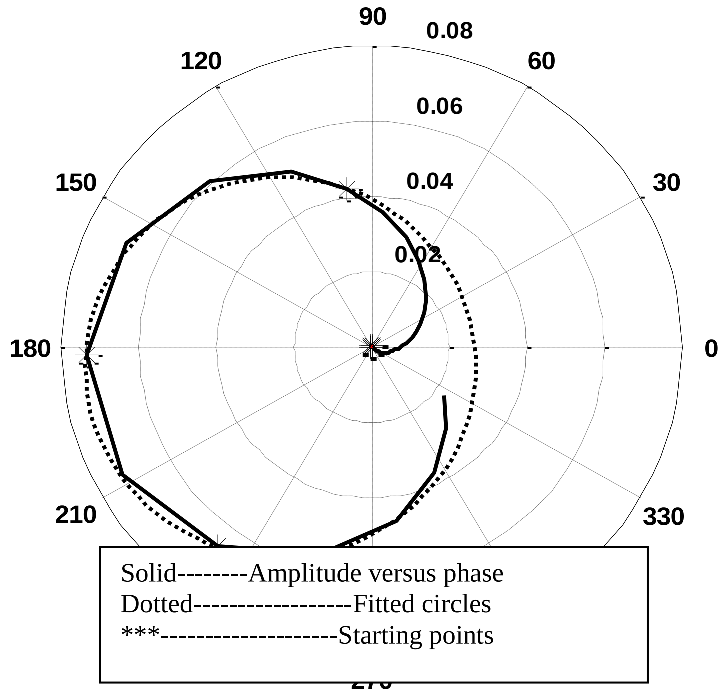


Fig 7. The induced voltage at fundamental frequency by MoF and HB for $E_i = 0.35(V/m)$.

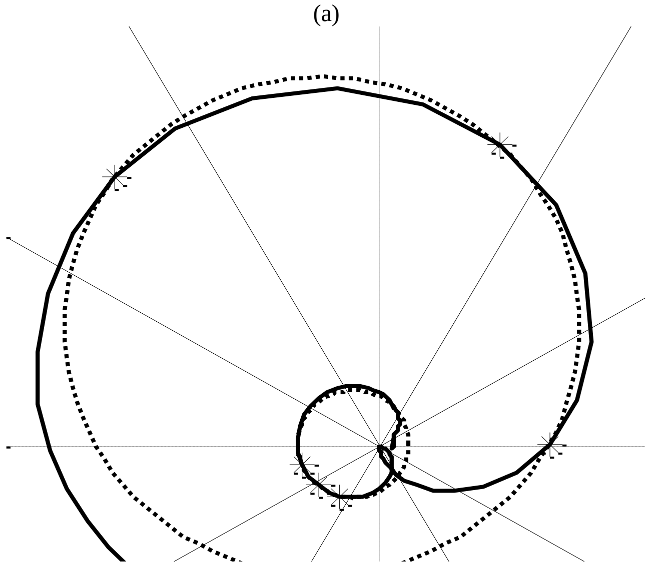
Since in Fig. 8(a) the radii of the second and third fitted circles are very small, and not easily seen, hence they are zoomed in and shown more clearly in Fig. 8(b). As shown in Fig. 8(a, b), three basic circles are making the overall shape. Therefore three sets of starting points around $L/\lambda = 0.25, 0.75, 1.25$ are again chosen to define the fitted circles.

The membership functions for modeling the partial locus and partial phase are shown in Figs. 9 and 10 respectively, and considered as the nonlinear behavior of the problem.

Now, using equation (6), the induced voltage at the third harmony versus L/λ is efficiently predicted as shown in Fig. 11. The effect of incident wave on the third harmony in the same manner with the first one is extractable. Since remained harmonies are much smaller, modeling them is thus neglected.



(a)



(b)

Fig 8. Amplitude versus phase of the induced voltage at third harmony in polar plane. (a): $L/\lambda \leq 0.6$,(b): $L/\lambda \geq 0.6$.

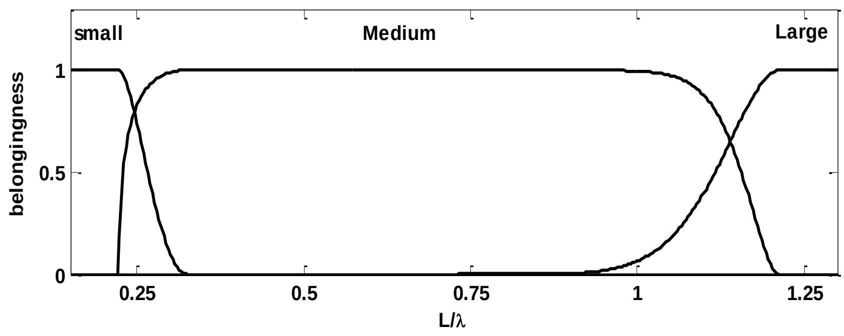


Fig 9. The membership functions for modeling the partial phase.

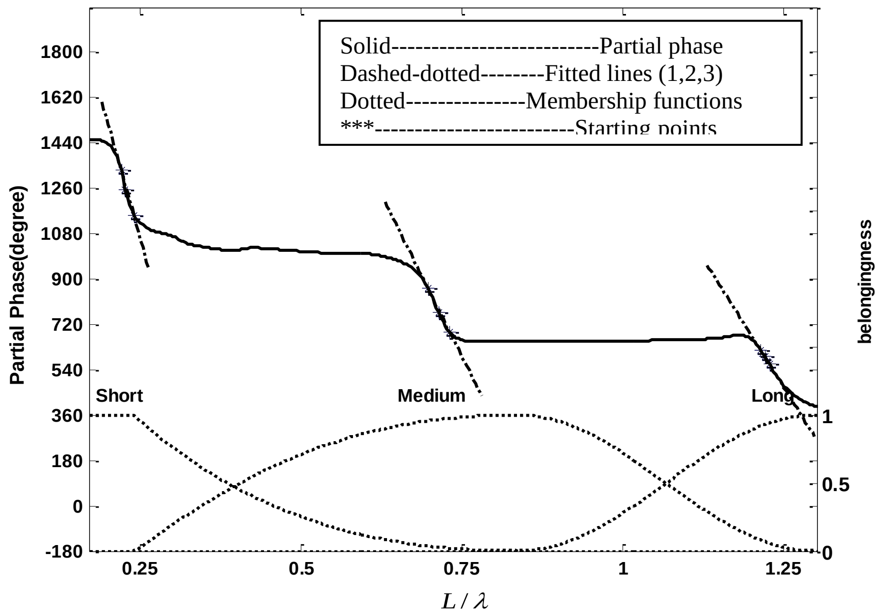


Fig 10. The membership functions for modeling partial phase.

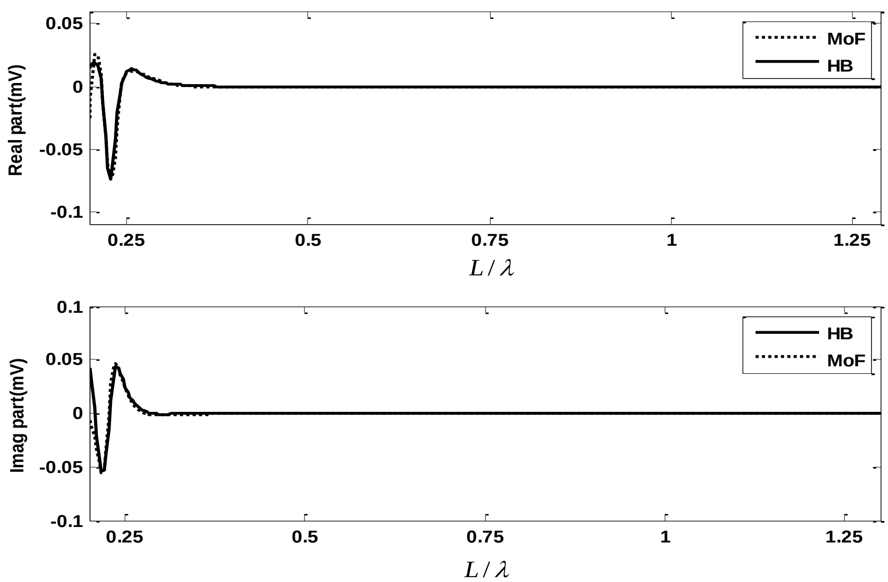


Fig 11. The predicted induced voltage at the third harmony by MoF and HB.

IV. Conclusion

In this contribution, nonlinear analysis of nonlinearly loaded antenna based upon the proposed approach by Tayarani [12] was carried out. Interesting features of this approach is firstly extracting behavior of the electromagnetic problem as simple and unchanged membership functions and secondly representing problem parameters as very simple curves. As a result, in despite of the existing nonlinear approaches such as harmonic balance technique, this approach is not sensitive to initial guess, and in addition it does not need to gradient operation in the iteration process. Therefore these make this approach so efficient. Analysis of nonlinearly loaded antenna array can be similarly carried out.

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REFERENCES

[1] T.K. Sarkar and D.D. Weiner, "Analysis of nonlinearly loaded multiport antenna structures over an imperfect ground plane using the Volterra-series method," *IEEE Trans. Electromag Compat*, vol. 20, no. 2, pp. 278–287, 1978.

[2] Tapan K. Sarkar et al, "Scattering analysis of nonlinearly loaded antennas", *IEEE Trans. Electromag Compat*, vol. 24, no. 2, pp. 125–131, 1976.

[3] C.C. huang and T.H. Chu, "Analysis of wire scatterers with nonlinear or time-harmonic loads in the frequency domain," *IEEE Trans. Antennas Propagat*, vol. 41, pp. 25–30, 1993.

[4] K.C. Lee, "Two efficient algorithms for the analyses of a nonlinearly loaded antenna and antenna array in the frequency domain," *IEEE Trans. Electromag Compat*, vol. 45, pp. 339–346, 2000.

[5] K. C. Lee, "Genetic algorithm based analyses of nonlinearly loaded antenna arrays including mutual coupling," *IEEE Trans. Antennas Propagat*, vol. 51, pp: 776–781, 2003.

[6] K. C. Lee, and Tsung-Non Lin, "Application of Neural Networks to Analyses of Nonlinearly Loaded Antenna Arrays Including Mutual Coupling Effects", *IEEE Trans on Antennas and Propagations*, vol. 53, no. 3, March 2005.

[7] K. C. Lee, "Application of neural networks and its extension of derivative to scattering from a nonlinearly loaded antenna," *IEEE Transactions on Antennas and propagation*, vol. 55, no. 3, pp. 1126-1132, March 2007.

[8] K. C. Lee, "mutual coupling mechanisms within arrays of nonlinear antennas," *IEEE Trans.* Electromag Compat, vol. 47, pp. 963–970, 2005.

[9] K. Sheshyekani, S. H. Sadeghi, and R. Moini, "A combined MoM-AOM approach for frequency domain analysis of nonlinearly loaded antennas in the presence of a lossy ground," *IEEE Trans. Antennas Propagat*, vol. 56, pp. 1717–1724, 2008.

[10] R.F. Harrington, Field Computation by Moment Methods, Macmillan, New York, 1968.

[11] S.A. Mass, Nonlinear Microwave Circuits, Artech House, Norwood, MA, 1988.

[12] M. Tayarani, "A movel approach to analysis and modeling of engineering electromagnetic problems and its applications by Means of fuzzy inference methods based on new expressions for electromagnetic basic concepts," PhD dissertation, the University of Electro-Communications, Japan, March 2001.

[13] S. M. Taghavi and S. R. Ostadzadeh, "High frequency analysis of single overhead line terminated to grounded arrester using fuzzy fnference models," *Journal of Communication Engineering*, vol. 2, no. 3, Summer 2103.

[14] S. R. Ostadzadeh, M. Soleimani and M. Tayarani, "A fuzzy model for computing input impedance of two coupled dipole antennas in the echelon form," *Progress In Electromagnetic Research*, *PIER 78.* pp. 265-283, 2008.

[15] S. R Ostadzadeh, M. Tayarani, and M. Soleimani, "A hybrid model in analyzing nonlinearly loaded dipole antenna and finite antenna array in the frequency domain", *International Journal of RF and Microwave*, vol. 19, pp. 512–518, 2009.

[16] S. R Ostadzadeh, "An efficient hybrid model in analyzing nonlinearly loaded dipole antenna above lossy ground in the frequency domain", *Applied Complutational Electromagnetic Society* (*ACES) Journal*, vol. 28, no. 9, pp. 780–787, 2013.

[17] F. Taheri and S. R. Ostadzadeh, "Transient analysis of the single-conductor overhead lines connected to grid-grounded arrester under direct lightning by means of GA," *Journal of Communication Engineering*, vol. 3, no. 1, Jan-Jun 2104.

[18] Takagi, T. and M. Sugeno, "Fuzzy identification of systems and its application to modeling and control," *IEEE Trans. on Systems, Man, and Cybernetics*, vol. SMC-15, no. 1, Jan./Feb. 1985.