ARTIFICIAL NEURAL NETWORK APPROACH: AN APPLICATION TO HARMONIC LOAD FLOW FOR RADIAL SYSTEMS

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ABSTRACT

Radial Distribution Systems (RDS) require special load flow methods to solve power flow equations owing to their high R/X ratio. Increasing use of power electronic devices and effect of magnetic saturation cause harmonics in RDS. This paper reports a multi-layer feed forward ANN with error back propagation learning algorithm for the calculation of bus voltages and power loss for different harmonic components. The proposed method is tested upon a 33-bus RDS and the results are reported for various harmonics. Extensive testing of the proposed ANN based approach indicates its viability for harmonic load flow assessment for radial systems.

KEYWORDS: Radial Distribution Systems; Harmonic components.

1. INTRODUCTION

Analysis of distribution system using power flow is important in the field of power systems. Distribution systems are predominantly characterized by their high R/X ratio and radial topology. Matrix based iterative methods do not lend themselves for radial distribution systems owing to these characteristics. Numerous algorithms have been developed using simple recursive equations [1-3].

Rapid industrialization has led to increasing use of power electronic devices in transmission and distribution systems. Modern industrial and domestic consumers use an ever-increasing number of devices that primarily employ power electronics based power-conditioners. Use of AC machines employing magnetic circuits in the saturation region also introduces harmonics in electrical power systems.

Many existing methods for distribution system load flow, fail to obtain a solution in several instances. Large RDS have complicated structure and are subject to changes in their topology frequently for maintenance, load balancing, network reconfiguration and emergency operations under the umbrella of Supervisory Control and Data Acquisition (SCADA). SCADA requires a fast Distribution Load Flow (DLF) algorithm that computes the voltage solution very rapidly for online scheduling.

Load flow calculation in harmonic polluted radial system with distributed generation has been carried out using abstract data types with complex parameters[4].

A multiple-frequency three-phase load-flow with two sub models including the fundamental power flow (FPF) and harmonic frequency power-flow (HPF) model has been developed and the standard Fourier analysis
was used to deal with the harmonic loads to
get injection currents [5]. Fuzzy number
based methodology for harmonic load-flow
calculation including uncertainties has been
applied for interconnected system[6].
Artificial neural network approach has been
applied for the radial distribution system
analysis [7]. From the above, one may see the
need for an efficient algorithm that reliably
and rapidly solves the power flow equations
for radial distribution systems characterized
by high R/X ratio, radial topology and for
various harmonic loads.
In this paper an ANN based harmonic load
flow solution technique for the radial system
has been developed. A database consisting of
different load patterns and the corresponding
voltage solution with the power loss is created
for third, fifth and seventh order of harmonics
using ladder iterative technique. The neural
network is trained to learn the features of the
load to estimate the bus voltage, angle and the
total loss. The trained neural network can be
instantly recalled to give output for an
untrained set of inputs without going through
the conventional iterative procedure, and that
saves considerable execution time especially
on a large systems.
The proposed method makes use of multi-
layer feed forward ANN with error back
propagation learning algorithm for the
calculation of bus voltages and power loss for
different harmonic components.
In section 2, a simple ladder network
technique is explained for solving the radial
system power balance equations. Using this
technique, a data base providing information
of the possible real and reactive power
demands for various harmonics at different
buses and their corresponding voltage
solution is created. Section 3 briefly
introduces the Back Propagation Network, its
architecture, training algorithm and
recognition phase. Section 4 discusses an
implementation of BPN for determining the
bus voltages for various harmonics. Section 5
presents the results of sample systems being
studied by the proposed method for different
harmonics. Section 6 presents the conclusion.

2. LADDER ITERATIVE TECHNIQUE

It is assumed that the ladder network
parameters for lines, loads and substation
voltage V_S are known. The voltage solution of
this network can be obtained by repeating the
forward and backward sweeps iteratively.
2.1 FORWARD SWEEP:
Compute bus voltages and associated currents
starting from last bus to the first bus.
\[
I_i = \left( \frac{S_i}{V_s} \right)
\]
\[
I_{i+1} = I_i + I_{i+1} \quad \text{for } i = 4, 3, 2, 1.
\]
\[
V_i = V_{i+1} + Z_{i+1} * I_{i+1}
\]
For i=5, V_5 is assumed to be V_S in the first
iteration and equals the value computed in
the backward sweep in the subsequent
iterations. I_5 is computed using (1).
2.2 BACKWARD SWEEP:
The backward sweep starts from 2nd bus to the
last bus (5th bus). Taking V_1=V_S. The i\textsuperscript{th}
bus voltages are computed as below using current
values computed in the forward sweep:
\[
V_i = V_{i+1} + Z_{i+1} * I_{i+1} \quad \text{for } i = 2, 3, 4, 5.
\]
The forward and backward sweeps are
continued until the difference between the
specified voltage at source and computed
voltage in the forward sweep is within the
tolerance limit.
3. BPN ARCHITECTURE

The most common BPN architecture is presented in Fig. 2. It is shown to have three layers, namely, input, hidden and output layers. Other applications may have several hidden layers. During training, several sets of input and their corresponding output vectors are considered. The training phase is used to determine the weights between the input, hidden and output layers.

The neurons used in the study use the sigmoid activation function defined by the following equation:

\[
\text{output} = \frac{1.0}{1.0 + e^{-\alpha v}}
\]

(3)

where \(\alpha\) is the abruptness of the sigmoid function and \(v\) is the total input to the neuron.

Let the vector \(\mathbf{X}\) represent an input to the input layer as shown in the Fig. 2. The net input at the hidden layers is computed by the matrix equation as below:

\[
\mathbf{V}_H = [WH] \mathbf{X}
\]

(4)

where \(WH_{ji}\) denotes the weight between \(i^{th}\) input layer node and \(j^{th}\) hidden layer node.

The output of the hidden layer nodes are given by

\[
\mathbf{Y}_H = \Phi (\mathbf{V}_H)
\]

(5)

where \(\Phi\) is the appropriate activation function.

In a similar manner, the total input at the output layer is given by the following equation:

\[
\mathbf{V}_O = [WO] \mathbf{V}_H
\]

(6)

The output of the output layer node is given by

\[
\mathbf{Y} = \Phi (\mathbf{V}_o)
\]

(7)

The steps for well-established training algorithm based upon Newton’s steepest descent technique is given below:

1. Read the training set and randomly initialize the weights. Set iteration index \(n=1\).
2. Set training set index \(\rho=1\).
3. Propagate \(\mathbf{X}_\rho\) through the network.
4. Determine the error vector of the \(\rho^{th}\) training set \(\mathbf{E}_\rho = \mathbf{O}_\rho - \mathbf{Y}_\rho\) where \(\mathbf{O}_\rho\) is the vector of expected output.
5. Correct the weights using Newton’s steepest descent technique.
6. If \(\rho < \text{number training sets} \ P\), set \(\rho = \rho+1\) and go to step 3.
7. If \(\sum_{\rho=1}^{P} |\mathbf{E}_{\rho}|^2 > \text{tolerance} \ \varepsilon\), increment the iteration index \(n\) and go to step 2.

The above method works well and has been well documented. The method requires that, the input and output to be from a continuous domain. Further, it also requires that the input and output set of vectors are non-contradictory for a successful training and operational function.

The RDS under study consists of 33 buses. The substation transformer is connected to bus 1 and there is no direct loading at bus1. The voltage at bus 1 is known and is specified as 1.0 per unit. The resistance and reactance of lines between any two buses and the base load condition is mentioned in table 1.
4. IMPLEMENTATION OF BPN TO DETERMINE HARMONIC LOAD FLOW SOLUTION

The input vector for the BPN is the real and reactive power loads for different harmonics at various buses of the power system. The resistance of the different lines remains the same for different harmonics while the reactance changes according to the order of harmonics. Load flow solution for different load patterns is obtained using ladder iterative technique with the relevant impedance component for the third, fifth and seventh order harmonics.

Sixty sets of loads were created by the following scheme:
(a) Varying both the real and reactive power loads simultaneously at all the load buses of the radial system.
(b) Varying both the real and reactive power loads simultaneously at a single load bus of the radial system.
(c) Varying only the real power load at a single load bus of the radial system.
(d) Varying only the reactive power load at a single load bus of the radial system.

Equation (8) and (9) represents the train input and train target matrix for a particular order of harmonics.

\[
\begin{align*}
P_{1,1} & P_{2,1} & P_{60,1} \\
P_{1,2} & P_{2,2} & P_{60,2} \\
P_{1,3} & P_{2,3} & P_{60,3} \\
& & \\
P_{1,32} & P_{2,32} & P_{60,32}
\end{align*}
\]

\[
\begin{align*}
Q_{1,1} & Q_{2,1} & Q_{60,1} \\
Q_{1,2} & Q_{2,2} & Q_{60,2} \\
Q_{1,3} & Q_{2,3} & Q_{60,3} \\
& & \\
Q_{1,32} & Q_{2,32} & Q_{60,32}
\end{align*}
\]

Train Input = (8)

\[
\begin{align*}
\delta_{1,1} & \delta_{2,1} & \delta_{60,1} \\
\delta_{1,2} & \delta_{2,2} & \delta_{60,2} \\
\delta_{1,3} & \delta_{2,3} & \delta_{60,3} \\
& & \\
\delta_{1,32} & \delta_{2,32} & \delta_{60,32}
\end{align*}
\]

Train Target = (9)

Where \( V_{ij} \) and \( \delta_{ij} \) represents the voltage and corresponding angle solution at the \( j \)th load of the \( i \)th load pattern for the particular order of harmonics. \( PL_i \) represents the total loss for the \( j \)th load pattern for the particular order of harmonics calculated from the ladder iterative technique.

For the multi layer feed forward ANN, tan-sigmoid transfer function (TANSIG) is used as activation function. For the considered 33 bus system, 64 input layer nodes (32+32, for real and reactive powers at each bus, there is no direct load connected at bus 1) and 65 output layer nodes are used. (32+32+1, for voltage magnitude and angle at each bus. The voltage magnitude angle is specified at the substation, the last node represents the power loss for the particular load condition).

After successful training of the ANN it should be able to produce the bus voltage magnitude with angle and the total power loss for any of
the untrained input load pattern with minimum time and maximum accuracy.

5. RESULTS AND DISCUSSION

A 33 bus radial distribution system Fig. 3 was tested using the proposed method. The power flow equations were solved using the ladder iterative technique explained in section 2. In order to achieve a broad representation of the power system in the Back Propagation Network, approximately sixty input-output vector pairs were generated for each of the harmonics for the considered 33-bus system. The BPN was trained in MATLAB® environment and the trained result for third harmonics is shown in Fig. 4. Thereafter, the BPN is ready for use. The results from the conventional harmonic load flow solution and from the trained ANN for different harmonics are shown in Table 2. The method seems to work well and is found to be very efficient and fast. The execution time to reach the voltage solution from the trained ANN is approximately one third of the execution time of the conventional method. The bus voltages and the power loss from BPN for the test inputs for the different order of harmonics are compared with ladder iterative technique solution and is listed in table 2.

For the minor changes in the network from the far end of the source, will not affect the results very much. However if the system topology changed from the sending end side, the proposed approach will not work satisfactorily, since the considered system is radial. Effectiveness of the proposed method for the system topology changes can be considered for the future work. As long as if the ANN is trained with the sufficient data (it may be real or simulated) the outcome of the ANN will be the expected outcome.

6. CONCLUSIONS

This paper presents a well defined approach to determine the harmonic load flow solution of a radial distribution system for various order of harmonics. Since collecting data from
the real system with harmonic sources for a large system is a difficult task, a 33 bus radial system is considered for analysis. Several load sets were considered and their solution was assessed using the conventional method of ladder network technique. Then using these sets of input and output vector pairs, the Back Propagation Network is trained. Thereafter, the BPN is ready for use wherein, given a harmonic load, it gives out the voltage solution with minimum time and maximum accuracy.

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### Table 1: System Under Study

| S. No. | From Bus | To Bus | R (Ω) | X (Ω) | P (kW) | Q (kvar) | V (p.u.) |
|--------|----------|--------|-------|-------|--------|----------|----------|
| 1      | 1        | 2      | 0.0922| 0.047 | 100    | 60       | 1        |
| 2      | 2        | 3      | 0.493 | 0.251 | 90     | 40       | 0.997    |
| 3      | 3        | 4      | 0.366 | 0.186 | 120    | 80       | 0.9829   |
| 4      | 4        | 5      | 0.3811| 0.194 | 60     | 30       | 0.9754   |
| 5      | 5        | 6      | 0.819 | 0.707 | 60     | 20       | 0.9679   |
| 6      | 6        | 7      | 0.1872| 0.618 | 200    | 100      | 0.9495   |
| 7      | 7        | 8      | 1.7114| 1.235 | 200    | 100      | 0.946    |
| 8      | 8        | 9      | 1.03  | 0.74  | 60     | 20       | 0.9323   |
| 9      | 9        | 10     | 1.044 | 0.74  | 60     | 20       | 0.926    |
| 10     | 10       | 11     | 0.1966| 0.065 | 45     | 30       | 0.9201   |
| 11     | 11       | 12     | 0.3744| 0.123 | 60     | 35       | 0.9192   |
| 12     | 12       | 13     | 1.468 | 1.155 | 60     | 35       | 0.9177   |
| 13     | 13       | 14     | 0.5416| 0.712 | 120    | 80       | 0.9115   |
| 14     | 14       | 15     | 0.591 | 0.526 | 60     | 10       | 0.9092   |
| 15     | 15       | 16     | 0.7463| 0.545 | 60     | 20       | 0.9078   |
| 16     | 16       | 17     | 1.289 | 1.721 | 60     | 20       | 0.9064   |
| 17     | 17       | 18     | 0.732 | 0.574 | 90     | 40       | 0.9043   |
| 18     | 2        | 19     | 0.164 | 0.156 | 90     | 40       | 0.9037   |
| 19     | 19       | 20     | 1.5042| 1.355 | 90     | 40       | 0.9965   |
| 20     | 20       | 21     | 0.4095| 0.478 | 90     | 40       | 0.9929   |
| 21     | 21       | 22     | 0.7089| 0.937 | 90     | 40       | 0.9922   |
| 22     | 3        | 23     | 0.4512| 0.308 | 90     | 50       | 0.9916   |
| 23     | 23       | 24     | 0.898 | 0.709 | 420    | 200      | 0.9793   |
| 24     | 24       | 25     | 0.896 | 0.701 | 420    | 200      | 0.9726   |
| 25     | 6        | 26     | 0.203 | 0.103 | 60     | 25       | 0.9693   |
| 26     | 26       | 27     | 0.2842| 0.144 | 60     | 25       | 0.9475   |
| 27     | 27       | 28     | 1.059 | 0.933 | 60     | 20       | 0.945    |
| 28     | 28       | 29     | 0.8042| 0.700 | 120    | 70       | 0.9335   |
| 29     | 29       | 30     | 0.5075| 0.258 | 200    | 600      | 0.9253   |
| 30     | 30       | 31     | 0.9744| 0.965 | 150    | 70       | 0.9217   |
| 31     | 31       | 32     | 0.3105| 0.361 | 210    | 100      | 0.9176   |
| 32     | 32       | 33     | 0.341 | 0.530 | 60     | 40       | 0.9167   |

Losses: 210.9983 kW
## TABLE 2A

3rd Harmonic, load = 1% of total load, voltage magnitude: 0.1pu

| Line number | Sending Bus | Receiving Bus | Resistance Ω | Reactance Ω | Real Power KW | Reactive Power KVAR | Voltage Solution from BPN in pu (conventional) | Voltage Solution in pu (conventional) | Percentage Accuracy |
|-------------|-------------|---------------|--------------|-------------|---------------|-------------------|-----------------------------------------------|----------------------------------------|---------------------|
| 1           | 1           | 2             | 0.0922       | 0.141       | 1             | 0.6               | 0.1000                                                       | 0.1000                                                | 100                 |
| 2           | 2           | 3             | 0.493        | 0.7533      | 0.9           | 0.4               | 0.0995                                                       | 0.0975                                                | 99.98               |
| 3           | 3           | 4             | 0.366        | 0.5592      | 1.2           | 0.8               | 0.0972                                                       | 0.0975                                                | 99.97               |
| 4           | 4           | 5             | 0.3811       | 0.5823      | 0.6           | 0.3               | 0.0960                                                       | 0.0958                                                | 99.98               |
| 5           | 5           | 6             | 0.819        | 2.121       | 0.6           | 0.2               | 0.0947                                                       | 0.0950                                                | 99.97               |
| 6           | 6           | 7             | 0.1872       | 1.8564      | 2             | 1                 | 0.0911                                                       | 0.0914                                                | 99.97               |
| 7           | 7           | 8             | 1.7114       | 3.7053      | 2             | 1                 | 0.0901                                                       | 0.0901                                                | 100                 |
| 8           | 8           | 9             | 1.03         | 2.22        | 0.6           | 0.2               | 0.0877                                                       | 0.0874                                                | 99.97               |
| 9           | 9           | 10            | 1.044        | 2.22        | 0.6           | 0.2               | 0.0866                                                       | 0.0870                                                | 99.96               |
| 10          | 10          | 11            | 0.1966       | 0.195       | 0.45          | 0.3               | 0.0856                                                       | 0.0850                                                | 99.94               |
| 11          | 11          | 12            | 0.3744       | 0.3714      | 0.6           | 0.35              | 0.0855                                                       | 0.0849                                                | 99.94               |
| 12          | 12          | 13            | 1.468        | 3.465       | 0.6           | 0.35              | 0.0852                                                       | 0.0852                                                | 100                 |
| 13          | 13          | 14            | 0.5416       | 2.1387      | 1.2           | 0.8               | 0.0841                                                       | 0.0837                                                | 99.96               |
| 14          | 14          | 15            | 0.591        | 1.578       | 0.6           | 0.1               | 0.0836                                                       | 0.0832                                                | 99.96               |
| 15          | 15          | 16            | 0.7463       | 1.635       | 0.6           | 0.2               | 0.0834                                                       | 0.0830                                                | 99.96               |
| 16          | 16          | 17            | 1.289        | 5.163       | 0.6           | 0.2               | 0.0831                                                       | 0.0835                                                | 99.96               |
| 17          | 17          | 18            | 0.732        | 1.722       | 0.9           | 0.4               | 0.0827                                                       | 0.0837                                                | 99.97               |
| 18          | 2           | 19            | 0.164        | 0.4695      | 0.9           | 0.4               | 0.0826                                                       | 0.0822                                                | 99.96               |
| 19          | 19          | 20            | 1.5042       | 4.0662      | 0.9           | 0.4               | 0.0994                                                       | 0.0994                                                | 100                 |
| 20          | 20          | 21            | 0.4095       | 1.4352      | 0.9           | 0.4               | 0.0989                                                       | 0.0994                                                | 99.95               |
| 21          | 21          | 22            | 0.7089       | 2.8119      | 0.9           | 0.4               | 0.0988                                                       | 0.0972                                                | 99.84               |
| 22          | 3           | 23            | 0.4512       | 0.9249      | 0.9           | 0.5               | 0.0986                                                       | 0.0976                                                | 99.9                |
| 23          | 23          | 24            | 0.898        | 2.1273      | 4.2           | 2                 | 0.0967                                                       | 0.0980                                                | 99.87               |
| 24          | 24          | 25            | 0.896        | 2.1033      | 4.2           | 2                 | 0.0956                                                       | 0.0956                                                | 100                 |
| 25          | 6           | 26            | 0.203        | 0.3102      | 0.6           | 0.25              | 0.0951                                                       | 0.0954                                                | 99.97               |
| 26          | 26          | 27            | 0.2842       | 0.4341      | 0.6           | 0.25              | 0.0907                                                       | 0.0927                                                | 99.8                |
| 27          | 27          | 28            | 1.059        | 2.8011      | 0.6           | 0.2               | 0.0902                                                       | 0.0912                                                | 99.9                |
| 28          | 28          | 29            | 0.8042       | 2.1018      | 1.2           | 0.7               | 0.0877                                                       | 0.0707                                                | 98.3                |
| 29          | 29          | 30            | 0.5075       | 0.7755      | 2             | 6                 | 0.0859                                                       | 0.0879                                                | 99.8                |
| 30          | 30          | 31            | 0.9744       | 2.889       | 1.5           | 0.7               | 0.0852                                                       | 0.0832                                                | 99.8                |
| 31          | 31          | 32            | 0.3105       | 1.0857      | 2.1           | 1                 | 0.0844                                                       | 0.0854                                                | 99.9                |
| 32          | 32          | 33            | 0.341        | 1.5906      | 0.6           | 0.4               | 0.0842                                                       | 0.0812                                                | 99.7                |
| Total Loss  | 2.3947KW    | Loss from BPN | 2.52KW       | 88.47%      |               |                   |                                                              |                                                       |                     |
### TABLE 2B

5th Harmonic, load = 0.5% of total load, voltage magnitude: 0.075pu

| Line number | Sending Bus | Receiving Bus | Resistance Ω | Reactance Ω | Real Power KW | Reactive Power KVAr | Voltage Solution in pu (conventional) | Voltage Solution from BPN in pu | Percentage Accuracy |
|-------------|-------------|---------------|--------------|-------------|---------------|---------------------|-------------------------------------|-------------------------------|---------------------|
| 1           | 1           | 2             | 0.0922       | 0.235       | 0.5           | 0.3                 | 0.0750                             | 0.0750                        | 100                 |
| 2           | 2           | 3             | 0.493        | 1.2555      | 0.45          | 0.2                 | 0.0745                             | 0.0723                        | 99.78               |
| 3           | 3           | 4             | 0.366        | 0.932       | 0.6           | 0.4                 | 0.0723                             | 0.0743                        | 99.8                |
| 4           | 4           | 5             | 0.3811       | 0.9705      | 0.3           | 0.15                | 0.0711                             | 0.0722                        | 99.89               |
| 5           | 5           | 6             | 0.819        | 3.555       | 0.3           | 0.1                 | 0.0698                             | 0.0596                        | 98.98               |
| 6           | 6           | 7             | 0.1872       | 3.094       | 1             | 0.5                 | 0.0658                             | 0.0648                        | 99.9                |
| 7           | 7           | 8             | 1.7114       | 6.1755      | 1             | 0.5                 | 0.0646                             | 0.0743                        | 99.03               |
| 8           | 8           | 9             | 1.03         | 3.7         | 0.3           | 0.1                 | 0.0621                             | 0.0635                        | 99.86               |
| 9           | 9           | 10            | 1.044        | 3.7         | 0.3           | 0.1                 | 0.0609                             | 0.0629                        | 99.8                |
| 10          | 10          | 11            | 0.1966       | 0.325       | 0.225         | 0.15                | 0.0598                             | 0.0548                        | 99.5                |
| 11          | 11          | 12            | 0.3744       | 0.619       | 0.3           | 0.175               | 0.0597                             | 0.0596                        | 99.9                |
| 12          | 12          | 13            | 1.468        | 5.775       | 0.3           | 0.175               | 0.0595                             | 0.0595                        | 100                 |
| 13          | 13          | 14            | 0.5416       | 3.5645      | 0.6           | 0.4                 | 0.0583                             | 0.0575                        | 99.92               |
| 14          | 14          | 15            | 0.591        | 2.63        | 0.3           | 0.05                | 0.0577                             | 0.0583                        | 99.94               |
| 15          | 15          | 16            | 0.7463       | 2.725       | 0.3           | 0.1                 | 0.0574                             | 0.0563                        | 99.89               |
| 16          | 16          | 17            | 1.289        | 6.605       | 0.3           | 0.1                 | 0.0572                             | 0.0532                        | 99.6                |
| 17          | 17          | 18            | 0.732        | 2.87        | 0.45          | 0.2                 | 0.0567                             | 0.0565                        | 99.98               |
| 18          | 18          | 19            | 0.164        | 0.7825      | 0.45          | 0.2                 | 0.0565                             | 0.0546                        | 99.81               |
| 19          | 19          | 20            | 1.5042       | 6.777       | 0.45          | 0.2                 | 0.0745                             | 0.0775                        | 99.7                |
| 20          | 20          | 21            | 0.4095       | 2.392       | 0.45          | 0.2                 | 0.0739                             | 0.0735                        | 99.96               |
| 21          | 21          | 22            | 0.7088       | 4.6865      | 0.45          | 0.2                 | 0.0738                             | 0.0733                        | 99.95               |
| 22          | 22          | 23            | 0.4512       | 1.5415      | 0.45          | 0.25                | 0.0737                             | 0.0735                        | 99.98               |
| 23          | 23          | 24            | 0.898        | 3.5455      | 2.1           | 1                   | 0.0718                             | 0.0735                        | 99.83               |
| 24          | 24          | 25            | 0.896        | 3.5055      | 2.1           | 1                   | 0.0708                             | 0.0608                        | 99                  |
| 25          | 25          | 26            | 0.203        | 0.517       | 0.3           | 0.125               | 0.0703                             | 0.0623                        | 99.2                |
| 26          | 26          | 27            | 0.2842       | 0.7235      | 0.3           | 0.125               | 0.0654                             | 0.0654                        | 100                 |
| 27          | 27          | 28            | 1.059        | 4.6685      | 0.3           | 0.1                 | 0.0649                             | 0.0609                        | 99.8                |
| 28          | 28          | 29            | 0.8042       | 3.503       | 0.6           | 0.35                | 0.0621                             | 0.0631                        | 99.9                |
| 29          | 29          | 30            | 0.5075       | 1.2925      | 1             | 3                   | 0.0601                             | 0.0631                        | 99.7                |
| 30          | 30          | 31            | 0.9744       | 4.815       | 0.75          | 0.35                | 0.0593                             | 0.0583                        | 99.9                |
| 31          | 31          | 32            | 0.3105       | 1.8095      | 1.05          | 0.5                 | 0.0585                             | 0.0485                        | 99                  |
| 32          | 32          | 33            | 0.341        | 2.651       | 0.3           | 0.2                 | 0.0582                             | 0.0602                        | 99.8                |

Total Loss: 1.189KW
Loss from BPN: 1.03KW

Percentage Accuracy: 84.1


### TABLE 2C

7th Harmonic, load = 0.25% of total load, voltage magnitude: 0.0.05pu

| Line number | Sending Bus | Receiving Bus | Resistance Ω | Reactance Ω | Real Power KW | Reactive Power KVAR | Voltage Solution from BPN in pu (conventional) | Percentage Accuracy |
|-------------|-------------|---------------|--------------|-------------|---------------|---------------------|-----------------------------------------------|--------------------|
| 1           | 1           | 2             | 0.0922       | 0.329       | 0.25          | 0.15                | 0.0500                                       | 99.9               |
| 2           | 2           | 3             | 0.493        | 1.7577      | 0.225         | 0.1                 | 0.0494                                       | 99.89              |
| 3           | 3           | 4             | 0.366        | 1.3048      | 0.3            | 0.2                 | 0.0467                                       | 99.89              |
| 4           | 4           | 5             | 0.3811       | 1.3587      | 0.15           | 0.075               | 0.0450                                       | 100                |
| 5           | 5           | 6             | 0.819        | 4.949       | 0.15           | 0.05                | 0.0433                                       | 99.89              |
| 6           | 6           | 7             | 0.1872       | 4.3316      | 0.5            | 0.25                | 0.0376                                       | 99.9               |
| 7           | 7           | 8             | 1.7114       | 8.6457      | 0.5            | 0.25                | 0.0356                                       | 99.9               |
| 8           | 8           | 9             | 1.03         | 5.18        | 0.15           | 0.05                | 0.0320                                       | 99.97              |
| 9           | 9           | 10            | 1.044        | 5.18        | 0.15           | 0.05                | 0.0302                                       | 99.89              |
| 10          | 10          | 11            | 0.1966       | 0.455       | 0.1125         | 0.075               | 0.0286                                       | 99.9               |
| 11          | 11          | 12            | 0.3744       | 0.8666      | 0.15           | 0.0875              | 0.0285                                       | 99.8               |
| 12          | 12          | 13            | 1.468        | 8.085       | 0.15           | 0.0875              | 0.0282                                       | 99.8               |
| 13          | 13          | 14            | 0.5416       | 4.9903      | 0.3            | 0.2                 | 0.0263                                       | 99.87              |
| 14          | 14          | 15            | 0.591        | 3.682       | 0.15           | 0.025               | 0.0254                                       | 99.9               |
| 15          | 15          | 16            | 0.7463       | 3.815       | 0.15           | 0.05                | 0.0249                                       | 99.89              |
| 16          | 16          | 17            | 1.289        | 12.047      | 0.15           | 0.05                | 0.0245                                       | 99.9               |
| 17          | 17          | 18            | 0.732        | 4.018       | 0.225          | 0.1                 | 0.0236                                       | 100                |
| 18          | 18          | 19            | 0.164        | 1.0955      | 0.225          | 0.1                 | 0.0234                                       | 99.96              |
| 19          | 19          | 20            | 1.5042       | 9.4878      | 0.225          | 0.1                 | 0.0494                                       | 99.9               |
| 20          | 20          | 21            | 0.4095       | 3.3488      | 0.225          | 0.1                 | 0.0488                                       | 99.8               |
| 21          | 21          | 22            | 0.7089       | 6.5611      | 0.225          | 0.1                 | 0.0487                                       | 99.9               |
| 22          | 22          | 23            | 0.4512       | 2.1581      | 0.225          | 0.125               | 0.0486                                       | 99.88              |
| 23          | 23          | 24            | 0.898        | 4.9637      | 1.05           | 0.5                 | 0.0461                                       | 99.9               |
| 24          | 24          | 25            | 0.896        | 4.9077      | 1.05           | 0.5                 | 0.0451                                       | 99.91              |
| 25          | 25          | 26            | 0.203        | 0.7238      | 0.15           | 0.0625              | 0.0445                                       | 99                |
| 26          | 26          | 27            | 0.2842       | 1.0129      | 0.15           | 0.0625              | 0.0371                                       | 99.94              |
| 27          | 27          | 28            | 1.059        | 6.5359      | 0.15           | 0.05                | 0.0365                                       | 99.97              |
| 28          | 28          | 29            | 0.8042       | 4.9042      | 0.3            | 0.175               | 0.0325                                       | 99.96              |
| 29          | 29          | 30            | 0.5075       | 1.8095      | 0.5            | 1.5                 | 0.0297                                       | 99.98              |
| 30          | 30          | 31            | 0.9744       | 6.741       | 0.375          | 0.175               | 0.0287                                       | 99.89              |
| 31          | 31          | 32            | 0.3105       | 2.5333      | 0.525          | 0.25                | 0.0273                                       | 99.97              |
| 32          | 32          | 33            | 0.341        | 3.7114      | 0.15           | 0.1                 | 0.0270                                       | 99.88              |

| System Parameters | Load | Voltage Solution from BPN in pu | Percentage Accuracy |
|-------------------|------|----------------------------------|--------------------|
| Total Loss        | 0.9358KW | Loss from BPN 0.84KW               | 90.42              |
تطبيق أساليب عشب العصب الصناعي على سريان الامال في الأنظمة المحورية في ظل توافقات غير مرغوب فيها

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المختصر:

تتطلب الأنظمة المحورية توزيع الطاقة طرق خاصة لسريان الامال وكي يحل مساعيات سريان القوي. نزيدة استعمال الأجهزة الإلكترونية وتأثير التشيح المغناطيسي آدى إلى ظهور توافقات غير مرغوب فيها في الأنظمة التوزيع المحورية.

تقدم هذه المقالة البحثية نظام متعدد الطبقات لتقنية الأتمام مع وجود برنامج لسريان الاختفاء في الاتجاه المعاكس وذلك لحساب الجهد وفقد القوة لأكثر من مركبة توافقة غير مرغوب فيها.

تم اختبار الطريقة المقترحة على 33 مسار للتوزيع المحوري وتم توضيح الطبقات لكل تردد من التوافقات غير المرغوب فيها. وقد اثبتت هذه الاختبارات للطريقة المقترحة جدوي هذه الطريقة لتقييم سريان الامال في الأنظمة المحورية في وجود توافقات غير مرغوب فيها.