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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

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was used to deal with the harmonic loads to get injection currents [5]. Fuzzy number based methodology for harmonic load-flow calculation including uncertainities 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.

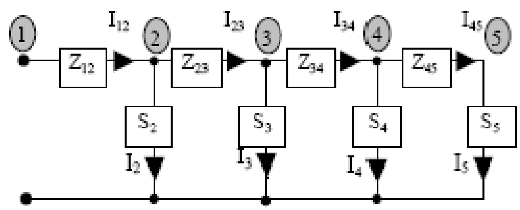

Fig. 1. Ladder Network

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.

$$\left.\begin{aligned} I_i &= (S_i/V_i)^* \\ I_{i-1,i} &= I_i + I_{i,i+1} \\ V_i &= V_{i+1} + Z_{i,i+1} * I_{i-1,i} \end{aligned}\right\} \text{for } i = 4, 3, 2, 1. \quad (1)$$

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 2[nd] bus to the last bus (5[th] bus). Taking $V_1=V_S$. The i[th] bus voltages are computed as below using current values computed in the forward sweep:

$$V_i = V_{i-1} + Z_{i-1,i} * I_{i-1,i} \quad \text{for } i = 2,3,4,5. \quad (2)$$

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:

$$\begin{bmatrix}\text{Neuron}\\ \text{output}\end{bmatrix} = \frac{1.0}{1.0+e^{-\alpha v}} \qquad (3)$$

where α is the abruptness of the sigmoid function and the v is the total input to the neuron.

Let the vector 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:

$$V_H = [WH]\,X \qquad (4)$$

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

$$Y_H = \Phi\,(V_H) \qquad (5)$$

where Φ is the appropriate activation function.

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

$$V_O = [WO]\,V_H \qquad (6)$$

The output of the output layer node is given by

$$Y = \Phi\,(V_O) \qquad (7)$$

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

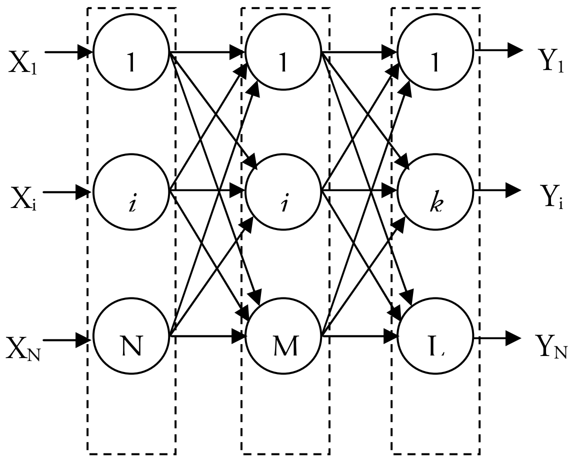

Fig. 2. Basic BPN Architecture

1. Read the training set and randomly initialize the weights. Set iteration index n=1.
2. Set training set index p=1.
3. Propagate X^p through the network.
4. Determine the error vector of the p^{th} training set
$E^p = O^p - Y^p$ where O^p is the vector of expected output.
5. Correct the weights using Newton's steepest descent technique.
6. If p < number training sets P, set $p = p+1$ and go to step 3.
7. If $\sum_{p=1}^{P} \left|E^p\right|^2 >$ tolerance ε, 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 where as 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.

$$\text{Train Input} = \begin{matrix} P_{1,1} & P_{2,1} & P_{60,1} \\ P_{1,2} & P_{2,2} & P_{60,2} \\ P_{1,3} & P_{2,3} & P_{60,3} \\ . & . & . \\ . & . & . \\ P_{1,32} & P_{2,32} & P_{60,32} \\ Q_{1,1} & Q_{2,1} & Q_{60,1} \\ Q_{1,2} & Q_{2,2} & Q_{60,2} \\ Q_{1,3} & Q_{2,3} & Q_{60,3} \\ . & . & . \\ . & . & . \\ Q_{1,32} & Q_{2,32} & Q_{60,32} \end{matrix} \quad (8)$$

Where $P_{i,j}$ and $Q_{i,j}$ represents the real and reactive power demands at the j^{th} bus of the i^{th} load pattern for the particular order of harmonics.

$$\text{Train Targe} = \begin{matrix} V_{1,1} & V_{2,1} & V_{60,1} \\ V_{1,2} & V_{2,2} & V_{60,2} \\ V_{1,3} & V_{2,3} & V_{60,3} \\ . & . & . \\ . & . & . \\ . & . & . \\ V_{1,32} & V_{2,32} & V_{60,32} \\ \delta_{1,1} & \delta_{2,1} & \delta_{60,1} \\ \delta_{1,2} & \delta_{2,2} & \delta_{60,2} \\ \delta_{1,3} & \delta_{2,3} & \delta_{60,3} \\ . & . & . \\ . & . & . \\ . & . & . \\ \delta_{1,32} & \delta_{2,32} & \delta_{60,32} \\ PL_1 & PL_2 & PL_{60} \end{matrix} \quad (9)$$

Where $V_{i,j}$ and $\delta_{i,j}$ represents the voltage and corresponding angle solution at the j^{th} bus of the i^{th} load pattern for the particular order of harmonics. PL_i represents the total loss for the i^{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 bus1) and 65 output layer nodes are used. (32+32+1, for voltage magnitude and angle at each bus. The voltage magnitude and 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 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.

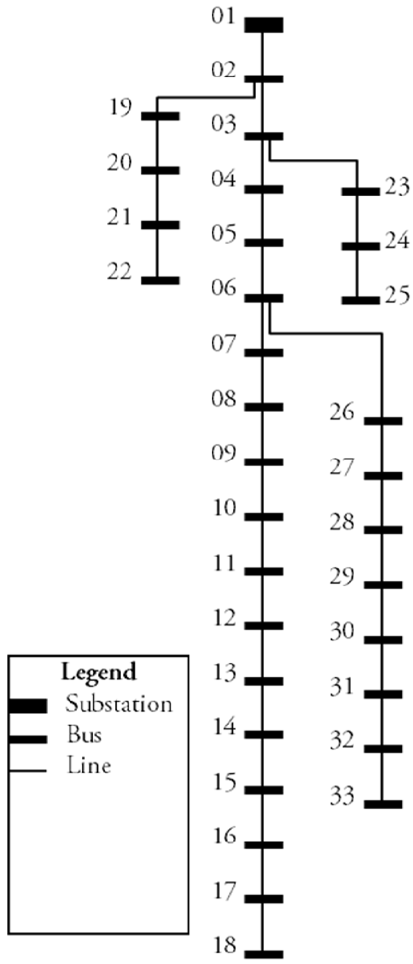

Fig.3. 33-bus radial distribution system

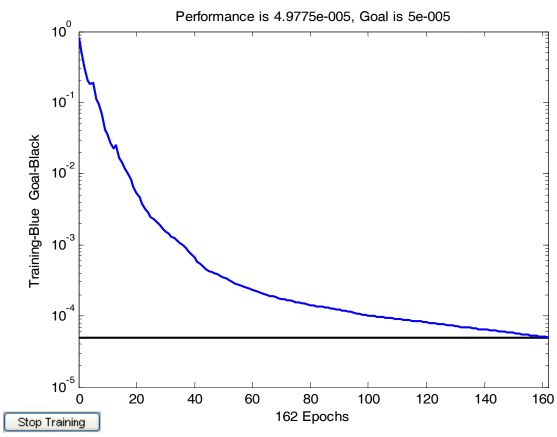

Fig.4. BPN Training Results for third harmonics

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)	Fundamental			
				X (Ω)	P (kW)	Q (kvar)	V (p.u.)
1	1	2	0.0922	0.047	100	60	1
2	2	3	0.493	0.2511	90	40	0.997
3	3	4	0.366	0.1864	120	80	0.9829
4	4	5	0.3811	0.1941	60	30	0.9754
5	5	6	0.819	0.707	60	20	0.9679
6	6	7	0.1872	0.6188	200	100	0.9495
7	7	8	1.7114	1.2351	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	0.1238	60	35	0.9192
12	12	13	1.468	1.155	60	35	0.9177
13	13	14	0.5416	0.7129	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	0.1565	90	40	0.9037
19	19	20	1.5042	1.3554	90	40	0.9965
20	20	21	0.4095	0.4784	90	40	0.9929
21	21	22	0.7089	0.9373	90	40	0.9922
22	3	23	0.4512	0.3083	90	50	0.9916
23	23	24	0.898	0.7091	420	200	0.9793
24	24	25	0.896	0.7011	420	200	0.9726
25	6	26	0.203	0.1034	60	25	0.9693
26	26	27	0.2842	0.1447	60	25	0.9475
27	27	28	1.059	0.9337	60	20	0.945
28	28	29	0.8042	0.7006	120	70	0.9335
29	29	30	0.5075	0.2585	200	600	0.9253
30	30	31	0.9744	0.963	150	70	0.9217
31	31	32	0.3105	0.3619	210	100	0.9176
32	32	33	0.341	0.5302	60	40	0.9167
				Losses: 210.9983 kW			

TABLE 2A

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

System Parameters					Load			Voltage Solution from BPN in pu	Percentage Accuracy
Line number	Sending Bus	Receiving Bus	Resistance Ω	Reactance Ω	Real Power KW	Reactive Power KVAr	Voltage Solution in pu (conventional)		
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	0.0997	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	99.9
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	0.0834	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

System Parameters					Load				
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	3.535	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	99.99
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	8.605	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	2	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	0.7089	4.6865	0.45	0.2	0.0738	0.0733	99.95
22	3	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	6	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	0.0669	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		84.1

TABLE 2C

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

System Parameters					Load			Voltage Solution from BPN in pu	Percentage Accuracy
Line number	Sending Bus	Receiving Bus	Resistance Ω	Reactance Ω	Real Power KW	Reactive Power KVAr	Voltage Solution in pu (conventional)		
1	1	2	0.0922	0.329	0.25	0.15	0.0500	0.0490	99.9
2	2	3	0.493	1.7577	0.225	0.1	0.0494	0.0483	99.89
3	3	4	0.366	1.3048	0.3	0.2	0.0467	0.0456	99.89
4	4	5	0.3811	1.3587	0.15	0.075	0.0450	0.0450	100
5	5	6	0.819	4.949	0.15	0.05	0.0433	0.0422	99.89
6	6	7	0.1872	4.3316	0.5	0.25	0.0376	0.0386	99.9
7	7	8	1.7114	8.6457	0.5	0.25	0.0356	0.0346	99.9
8	8	9	1.03	5.18	0.15	0.05	0.0320	0.0323	99.97
9	9	10	1.044	5.18	0.15	0.05	0.0302	0.0313	99.89
10	10	11	0.1966	0.455	0.1125	0.075	0.0286	0.0276	99.9
11	11	12	0.3744	0.8666	0.15	0.0875	0.0285	0.0265	99.8
12	12	13	1.468	8.085	0.15	0.0875	0.0282	0.0262	99.8
13	13	14	0.5416	4.9903	0.3	0.2	0.0263	0.0250	99.87
14	14	15	0.591	3.682	0.15	0.025	0.0254	0.0244	99.9
15	15	16	0.7463	3.815	0.15	0.05	0.0249	0.0238	99.89
16	16	17	1.289	12.047	0.15	0.05	0.0245	0.0255	99.9
17	17	18	0.732	4.018	0.225	0.1	0.0236	0.0236	100
18	2	19	0.164	1.0955	0.225	0.1	0.0234	0.0238	99.96
19	19	20	1.5042	9.4878	0.225	0.1	0.0494	0.0484	99.9
20	20	21	0.4095	3.3488	0.225	0.1	0.0488	0.0468	99.8
21	21	22	0.7089	6.5611	0.225	0.1	0.0487	0.0477	99.9
22	3	23	0.4512	2.1581	0.225	0.125	0.0486	0.0486	100
23	23	24	0.898	4.9637	1.05	0.5	0.0461	0.0451	99.9
24	24	25	0.896	4.9077	1.05	0.5	0.0451	0.0442	99.91
25	6	26	0.203	0.7238	0.15	0.0625	0.0445	0.0345	99
26	26	27	0.2842	1.0129	0.15	0.0625	0.0371	0.0377	99.94
27	27	28	1.059	6.5359	0.15	0.05	0.0365	0.0368	99.97
28	28	29	0.8042	4.9042	0.3	0.175	0.0325	0.0321	99.96
29	29	30	0.5075	1.8095	0.5	1.5	0.0297	0.0295	99.98
30	30	31	0.9744	6.741	0.375	0.175	0.0287	0.0289	99.98
31	31	32	0.3105	2.5333	0.525	0.25	0.0273	0.0270	99.97
32	32	33	0.341	3.7114	0.15	0.1	0.0270	0.0258	99.88
				Total Loss	0.9358KW	Loss from BPN	0.84KW		90.42

تطبيق أسلوب شبكات العصب الصناعي على سريان الاحمال في الانظمة المحورية في ظل توافقيات غير مرغوب فيها

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الملخص:

تتطلب الانظمة المحورية لتوزيع الطاقة طرق خاصة لسريان الاحمال لكي يحل معادلات سريان القوي. نبزيادة استعمال الاجهزة الالكترونية وتأثير التشبع المغناطيسي أدي الى ظهور توافقيات غير مرغوب فيها في انظمة التوزيع المحورية.

تقدم هذه المقالة البحثية نظام متعدد الطبقات للتغذية الامامية مع وجود برنامج لسريان الاخطاء في الاتجاه المعاكس وذلك لحساب الجهد وفقد القوة لاكثر من مركبة توافقية غير مرغوب فيها.

تم اختبار الطرقة المقترحة على ٣٣ مسار للتوزيع المحوري وتم تبويب النتائج طبقا لكل تردد من التوافقيات غير المرغوب فيها. وقد اثبتت هذه الاختبارات للطريقة المقترحة جدوي هذه الطريقة لتقييم سريان الاحمال في الانظمة الحورية في وجود توافقيات غير مرغوب فيها.