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RESEARCH ARTICLE

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Optimal location of interline power flow controller for controlling multi transmission line: A new integrated technique

Abstract In this paper, an interline power flow controller (IPFC) is used for controlling multi transmission lines. However, the optimal placement of IPFC in the transmission line is a major problem. Thus, we use a combination of tabu search (TS) algorithm and artificial neural network (ANN) in the proposed method to find out the best placement locations for IPFC in a given multi transmission line system. TS algorithm is an optimization algorithm and we use it in the proposed method to determine the optimum bus combination using line data. Then, using the optimum bus combination, the neural network is trained to find out the best placement locations for IPFC. Finally, IPFC is connected at the best locations indicated by the neural network. Furthermore, using Newton-Raphson load flow algorithm, the transmission line loss of the IPFC connected bus is analyzed. The proposed methodology is implemented in MATLAB working platform and tested on the IEEE-14 bus system. The output is compared with the genetic algorithm (GA) and general load flow analysis. The results are validated with Levenberg-Marquardt back propagation and gradient descent with momentum network training algorithm.

Keywords IEEE-14 bus system, interline power flow controller (IPFC), tabu search (TS) algorithm, artificial neural network (ANN), training algorithm, load flow

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1 Introduction

Power flow analysis is one of the major tasks in power system studies. The steady-state conditions of a power system are determined for a set of given power generations and load demand in power flow analysis [1,2]. The most vital objective of the power flow analysis is determining the real and reactive powers flowing in each line along with the magnitude and phase angle of the voltage at each bus of the system for a given loading condition [3]. The load-flow analysis gives the real and reactive power losses and voltages at various nodes of the power system, in addition to showing the steady-state electrical performance and power-flow of the system [4,5]. In recent times, the quick progress in the field of power electronics have resulted in the employment of flexible alternating current transmission system (FACTS) devices as one of the most effective means to develop power system operation controllability and power transfer limits [6].

FACTSs are power electronics based static equipments which progress the power controllability and the power transport capability of the AC transmission network [7]. A set of controllers, which can be applied individually or in coordination with others to control one or more of the interrupted system parameters, is known as FACTS technology [8]. Some types of FACTS devices available for this use are static var compensator (SVC), thyristor controlled series capacitor (TCSC), static synchronous series compensator (SSSC), static synchronous compensator (STATCOM), unified power flow controller (UPFC), and interline power flow controller (IPFC) [9].

For series compensation, the IPFC is a voltage source converter based FACTS controller which is used for controlling the power flow among the multi-line transmission systems of a substation, and it has exceptional capabilities [10]. It is an extension of UPFC that can efficiently control the transmission line parameters of interconnected systems [11]. It controls the power flow in transmission line by injecting active and reactive voltage components in series with the transmission line [12]. IPFC consists of two or more SSSCs with a common DC-link. While active power could be transferred via the DC-link between the compensated lines, it provides independent control of reactive power of each individual line [13].

Optimally placing the power flow controller decreases the transmission line loss and power generation expenses and increases the load capacity of the transmission system [14]. To maximize the load ability of transmission lines, the evolutionary algorithm has been applied for the optimal placement of multi-type FACTS devices [15]. Tabu search (TS) is a powerful optimization procedure to a number of combinatorial optimization problems that has been successfully applied. In local minima, it has the ability to avoid entrapment [16]. The optimal placement of IPFC is one of the challenging tasks for reducing transmission line losses and improving load capacity.

The optimal location of the IPFC is optimized by TS algorithm based hybrid technique in this paper. By evaluating the active power improvement in the system, the proposed approach is then analyzed as a result of placing IPFC at the locations indicated by the proposed system. The review of the recent research is presented in Section 2. Then, the systematical description of IPFC and the hybrid technique are described in Sections 3 and 4 in the rest of the paper. The implementation results are discussed in Section 5, and Section 6 concludes the paper.

2 Recent research works: A brief review

There are numerous related works on the subject of optimal placement and power flow analysis of IPFC in literature. Some of them are reviewed here. Zhang et al. [17] have presented a power injection model (PIM) of IPFC. This model is developed for power flow analysis. To achieve the specified control target, the IPFC state variables have been adjusted concurrently with the network state variables. The real and reactive power flows have been analyzed using PIM of the IPFC. Sankar et al. [18] have proposed an IPFC, which is a voltage source converter (VSC)-based FACTS controller for series recompense in power system with the unique ability of power management among the multi-lines of a substation. To develop the power flow and to provide a power balance in a transmission system, IPFC has been used. Vinkovic et al. [19] have proposed an approach to model an IPFC for power flow calculations. This is done by applying the Newton-Raphson (NR) method. In terms of the interpretation of the device's branches, they were offered approach differs from the methods planned by other authors. They were measured on the basis of their currents, and so it could, as a result, be denoted as a current-based model of an IPFC.

Usha Rani et al. [20] have proposed a power flow model. This is developed for IPFC, and simulation of interline power flow controller was done using the planned power flow model. Asad et al. [21] have proposed a method for organizing the power flow in transmission lines by controlling IPFC based on its structure and performance and also the main beliefs of its control. Naresh Babu et al. [22], Kahyaei et al. [23], and Jilledi [24] have presented a mathematical model of IPFC, termed as PIM. This model was included in NR power flow algorithm to revise the power flow control in transmission lines, in which IPFC has been placed. Karthik et al. [25] have proposed a hybrid technique for identifying the proper place for fixing the IPFC by genetic algorithm (GA) and neural network (NN).

It is clear that less works are presented to solve the optimal placement problem of IPFC from the review of the recent research. The optimization processes are mainly based on the heuristic optimization algorithm, and the power flow is determined by PIM in presented works. The GA is a popular one among them, but the searching complexity of GA is superior to the TS algorithm. Thus, the optimization solution is ineffective due to the complexity and power transmission losses, and also the memory is increased. In addition, it may not capture the nonlinearity associated with the power system, due to the drawbacks of this PIM. The hybridized optimal IPFC location is described in the following section.

3 Systematical model of IPFC

IPFC is one of the FACTS devices, which is used for controlling the multi transmission lines of a transmission system. An IPFC consists of two series VSCs coupled by a DC voltage link. The DC-link is represented by a bidirectional link for active power exchange between the voltage sources. The VSC is used to transfer active power in the transmission lines and also to control transmission line losses. The VSC-based FACTS controller such as SSSC is used for the purpose of controlling the power flow in IPFC. The mathematical modeling of power flow in IPFC is derived using the NR method. The schematic diagram of a simple IPFC with two VSCs is shown in Fig. 1.

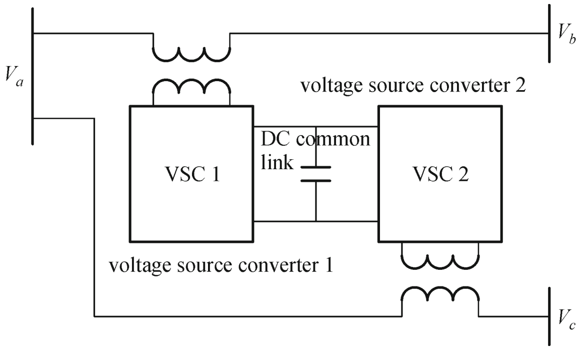


Fig. 1 Schematic diagram of IPFC

In this diagram, each series inverter controls the power flow by injecting fully controllable voltages, VSC 1 and VSC 2. The sending end bus voltage is V_a and the receiving end voltages are V_{ba} and V_{ca}. In this series-connected inverter, the power is generated externally. Thus, line losses cannot occur in this series connected VSC 1 and VSC 2. These two VSCs do not function under normal and abnormal line operating conditions. IPFC absorbs power from these VSCs and maintains the transmission line stability.

• Power injection model of IPFC

For calculating the injecting active power, voltage, and voltage angle in each bus, the power injection model of IPFC is useful. The power calculation is based on NR load flow algorithm. Before and after connecting the IPFC, it is used to check the loss variation. The equivalent circuit for the power injection model of IPFC is shown in Fig. 2.

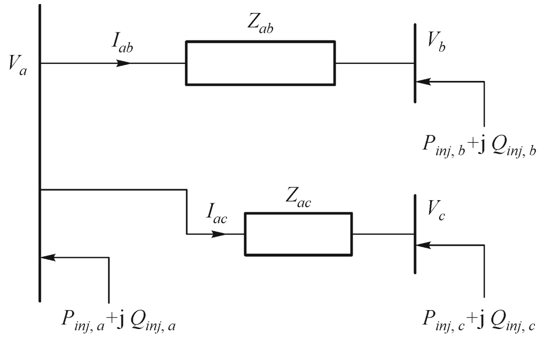


Fig. 2 Power flow model of IPFC

In this mathematical model, V_a, V_b, and V_c are the bus voltages of buses a, b, and c, respectively. Under normal condition, the real power across the two transmission lines is $R_e\left\{V_{ab}\overline{I}_{ab} + V_{ac}\overline{I}_{ac}\right\} = 0$. The impedance values of these two lines are Z_{ab} and Z_{ac}. The currents between the buses a, b and c are I_{ab} and I_{ac}, respectively.

The power flow in the injection model of IPFC is calculated by using the following equations:

$$\begin{aligned} P_a = {} & V_a^2 g_{aa} - \sum_{b=1,b\neq a}^{n} V_a V_b \left(g_{ab}\cos(\theta_b - \theta_a) + h_{ab}\sin(\theta_b - \theta_a)\right) \\ & - \sum_{b=1,b\neq a}^{n} V_a V_{inj,ab}\left(g_{ab}\cos(\theta_a - \theta_{inj,ab}) + h_{ab}\sin(\theta_a - \theta_{inj,ab})\right), \end{aligned} \tag{1}$$

$$\begin{aligned} Q_a = {} & V_a^2 h_{aa} - \sum_{b=1,b\neq a}^{n} V_a V_b \left(g_{ab}\sin(\theta_b - \theta_a) + h_{ab}\cos(\theta_b - \theta_a)\right) \\ & - \sum_{b=1,b\neq a}^{n} V_a V_{inj,ab}\left(g_{ab}\sin(\theta_a - \theta_{inj,ab}) + h_{ab}\cos(\theta_a - \theta_{inj,ab})\right), \end{aligned} \tag{2}$$

where, P_a and Q_a are the real and reactive powers at bus a, V_{inj} is the magnitude of injected voltage, θ_{inj} is the angle of injected voltage, g and h are the real and imaginary parts of bus admittance, n is the number of buses ($n = a$, b, and c).

4 Determination of optimal IPFC location by integrated technique

We used IPFC for controlling the transmission line and reducing the transmission losses in this paper. The determination of most favorable placement locations for IPFC is a complicated and difficult task. Therefore, to find out the optimal solution for placing IPFC in transmission line, here we introduced a hybrid technique. In the proposed hybrid method, TS algorithm and NN are the two techniques incorporated. To generate the training data set from the line data, TS is one of the optimization techniques used. The neural network is a training-based method and it is used in the proposed method to find out the optimum data set. To increase the power stability between the transmission lines and to reduce the transmission losses, this method is used.

4.1 TS-based data set creation

To decide the optimal placement of IPFC, TS is one of the mathematical oriented optimization which is used. An optimal network training data set is generated from the basic data of the selected bus system using the TS algorithm. The data set optimization is performed based on the maximum combination of buses, the real and reactive powers, and the loss of the corresponding buses. In the multi transmission line, these optimized combinations create more possible ways for connecting IPFC. The TS-based optimization algorithm has six basic steps: 1) initial solution, 2) trail solution, 3) set of candidate moves, 4) tabu functions, 5) aspiration criterion, and 6) stopping criteria.

The basic steps of TS algorithm are described briefly as follows:

Initial solution: From the database, a set of data set is selected at random such that one of the data set contains the slack bus. The bus parameters of the selected data sets excluding the slack bus are used as the base value for all iterations.

Trail solution: From this initial solution, the trail solution, i.e., all the combination of buses and lines can be developed. This trail solution is the central node of the next iteration.

Set of candidate moves: It is a set of all possible buses to which IPFC can be connected in the transmission lines. Thus, a set of solutions is obtained, which is a subset to the trail solutions. Hence, it reduces the number of trail solutions.

Tabu functions: The tabu function is then applied to the candidate moves, which is the selected subset of trail solutions, and checks the priority of all possible buses based on the number of lines connected to each bus and lists those buses that have a priority exceeding a minimum threshold. This list is called as tabu list. The listed buses, i.e., move solution is the local optimum solution of the visited node. The listed solution plays a great role in the search of high quality solutions. In this way, a good solution is identified from the listed buses.

Aspiration criterion (level): The objective function value is calculated for each bus presented in the tabu list. The objective function is the maximum number of bus combination. If the first bus is selected, its objective function value is acceptable. Otherwise, the objective function value of the bus that comes next in the list is examined and so on.

Stopping criteria: The above stated steps are repeated until the criterion of the pre-specified solution is satisfied by the obtained solution or the maximum number of iterations is reached.

Figure 3 gives the flow of the proposed TS algorithm.

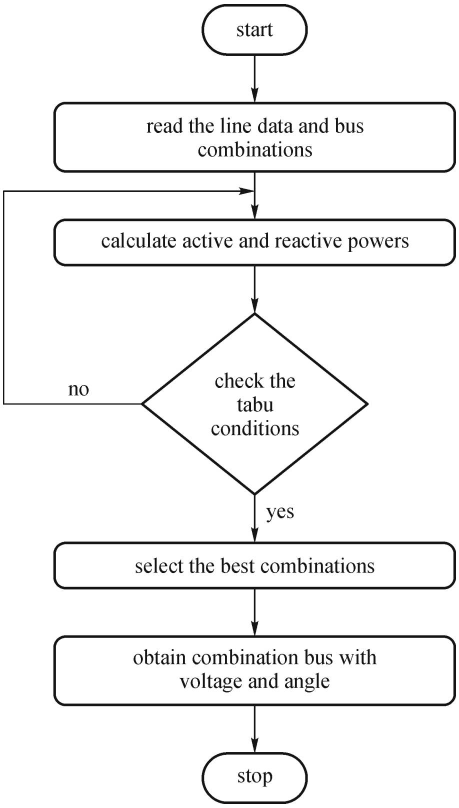


Fig. 3 Proposed TS algorithm for obtaining proper place for fixing the IPFC

4.2 Neural network training method

Complex manufacturing processes that have a number of variables and complex interactions utilize ANNs as outstanding tools. In a neural network, input layer, hidden layer, and output layer are the three layers that basically subsist. At this point, we use neural networks in two places. Initially, it is used to obtain various combinations of buses for the user specified number of lines to which the IPFC must be linked. Secondly, neural network is used to obtain the related voltage and angle that must be injected for the selected combination of buses. In the following sections the operation of each method is described.

4.2.1 Identification of IPFC connecting buses using neural network

Here, the neural network is trained using the optimized data set, and the buses for connecting IPFC are identified. There are three layers in the neural network. Each layer of neural network has some predefined number of neurons. The input layer has one variable, the hidden layer has N variables, and the output layer has $N+1$ variables. A gradient descent with momentum training algorithm is used to train the neural network. The optimum combination of IPFC connecting bus is obtained from the output of the neural network. The configuration of neural network is shown in Fig. 4, and the steps involved in the training process are described below.

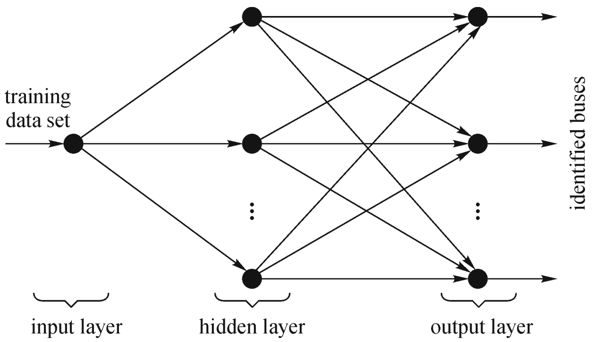


Fig. 4 Structure of neural network utilized in identification of IPFC connecting buses

Step 1 Initially, neuron input weights are initialized. Then, the optimized training data set is given as input to the neural network. The input layer of the network is denoted as L.

Step 2 The applied data set is trained with respect to their weight. The outputs of the neural network are denoted as $Q_1, Q_2, \ldots, Q_{N+1}$.

Step 3 The weights of all neurons are adjusted.

Step 4 Determine the buses to be connected.

4.2.2 Training for identifying real power, voltage, and angle

For connecting the IPFC, the output of the first neural network is used to decide the optimum bus. Now, the output of the first neural network is given as input to the second neural network. As the second neural network, a multi-layer type neural network is used. From the second neural network, bus voltage, voltage angle, and real power are obtained as output by giving the acknowledged buses as its input. This output is principally based on the loss reduction of the buses. Figure 5 gives the structure of the network utilized in identifying real power, voltage, and angle.

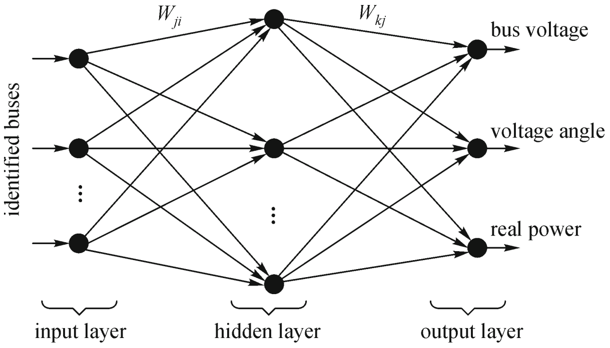


Fig. 5 Structure of network utilized in identifying real power, voltage, and angle

For each neuron j in the hidden layer, a function f of the sum of its input signals x_i after weighting them with the signals of the respective connections W_{ji} from the input layer is computed and obtained the output Y_j as following:

$$Y_j = f\left(\sum W_{ji} x_i\right), \tag{3}$$

where f is the active function, which is necessary to transform the weight of all neuron signals. In this neural network, the training weight is adjusted by the training algorithm. The neural network error function e can be written as

$$e = \sum_{k=1}^{p} \frac{1}{2(t_k - y_k)^2}, \tag{4}$$

where y_k is the actual output for the kth pattern, t_k is the desired output, and p is the total number of training patterns.

The training steps of the neural network are

Step 1 Present all inputs, i.e., identified buses to the network and compute the corresponding network outputs and errors.

Step 2 Set the weights of the network.

Step 3 Then, error is recomputed with respect to weight.

Step 4 Then, the bus voltage, voltage angle, and real power values are compared with the old values. If transmission loss is improved, then proceed to next step; otherwise, go back to Step 1.

Step 5 Select the bus combination for which the loss is low.

The network weight is updated according to the following formula:

$$W_{ji}(t+1) = W_{ji}(t) + \Delta W_{ji}(t). \tag{5}$$

For identifying the bus to which the IPFC must be associated, the training completed neural network is used. For this neural network, the number of buses in which the IPFC must be connected is given as input and the equivalent combination is obtained as output. The active power can be increased as well as the power can be balanced between the lines by connecting IPFC to those buses. The losses are reduced and this reduces the transmission cost due to the boost in active power.

4.3 Power flow calculation of IPFC

The power flow calculations of IPFC are performed using the basic load flow formulas. Using the basic formulas, the real power, bus voltage, and voltage angles are calculated for IPFC connected lines. Thus, the improvement in real power and the loss variation of the IPFC connected transmission lines are determined easily. Once the real power and transmission losses are determined, the amount of IPFC stabilized losses can be calculated. Several methods are available to solve the power flow of a system, and NR is one of the most popular methods. The general power flow solution of NR is explained in Ref. [25]. This process need to be continued until a predetermined condition is satisfied. A common stopping condition terminates, if the power mismatch equation is below the tolerance value.

5 Result and discussion

In MATLAB 7.10 platform, the planned technique is implemented and it is tested on IEEE-14 bus system. The tested IEEE-14 bus system is obtained from http://www.ee.washington.edu/research/pstca/pf14/pg_tca14bus.htm. The diagram of the tested bus system is shown in Fig. 6, and the output are exposed below.

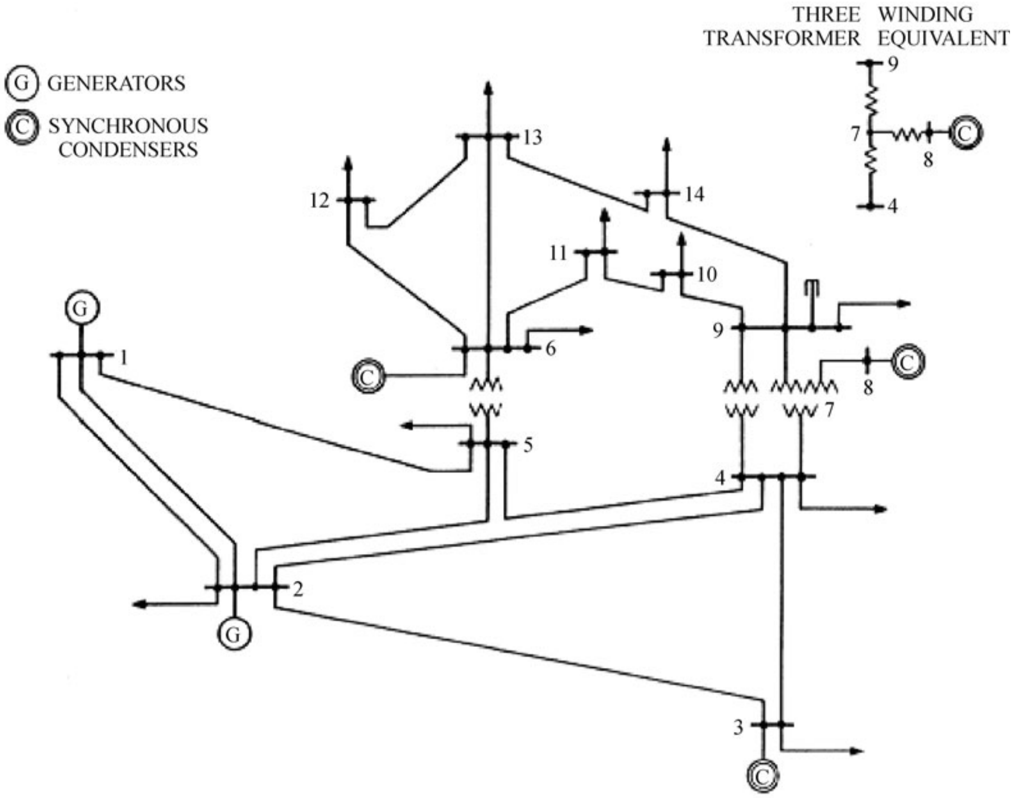


Fig. 6 IEEE-14 bus system

Bus 1 is selected as slack bus, Bus 2 is generated bus, and all other buses are load buses. The base voltage of slack bus is selected as 1 p.u. (per unit) and angle is selected as 0 in this tested system. In particular bus, the transmission line is selected based on the maximum number of lines connected. Subsequently, the real and reactive powers are injected based on Eqs. (1) and (2). Lastly, the power flow of the total system is analyzed. The total loss of the system is evaluated from the power flow analysis. The output of the power system is tabulated. Tables 1 and 2 are the bus and line data of IPFC connected in two lines. The two lines are selected from 7, 5, and 4 buses. Tables 3 and 4 are the bus and line data of IPFC connected in three lines. The IPFC connected lines are selected from bus numbers 6, 11, 12, and 13. Table 5 represents the voltage and angle of IPFC connected line. Table 6 illustrates the comparison of the outputs of TS, GA, and without using IPFC. Table 7 illustrates the comparison of the outputs of Levenberg-Marquardt back propagation and gradient descent with momentum network training algorithm.

The above tables indicate that the line loss of TS is lower than that of GA. In Table 7, the losses of two neural network training algorithms are analyzed. According to the changes of training algorithm, the identification performance of neural network is improved for placing IPFC. Hence, the loss of the gradient descent with momentum training algorithm which is used in this paper is reduced compared to Levenberg-Marquardt back propagation.

The network validation performance, the regression

Table 1 Bus data of IEEE-14 bus system obtained using proposed technique (IPFC connected in two lines)

NR load flow analysis

Bus No.	voltage/p.u.	angle/(°)	injection		generation		load	
			/MW	/Mvar	/MW	/Mvar	/MW	/Mvar
1	1.06	0	228.392	−14.654	228.392	−14.654	0	0
2	1.045	−4.8971	18.3	34.144	40	46.844	21.7	12.7
3	1.01	−12.5708	−93.674	8.317	0	27.532	93.674	19.215
4	1.0136	−10.0511	−47.518	3.989	0	0	47.518	−3.989
5	1.017	−8.5885	−7.484	−1.744	0	0	7.484	1.744
6	1.07	−14.1115	−10.911	15.932	0	23.552	10.911	7.62
7	1.0455	−12.9291	0.266	−0.314	0	0	−0.266	0.314
8	1.08	−12.9183	0.12	21.137	0	21.286	−0.12	0.149
9	1.0302	−14.4744	−29.218	−16.511	0	0	29.218	16.511
10	1.0295	−14.6443	−8.185	−6.338	0	0	8.185	6.338
11	1.0458	−14.4673	−3.097	−2.067	0	0	3.097	2.067
12	1.0532	−14.9117	−5.697	−1.867	0	0	5.697	1.867
13	1.0466	−14.967	−13.217	−5.918	0	0	13.217	5.918
14	1.019	−15.7183	−14.9	−5	0	0	14.9	5
total			13.176	29.106	268.392	104.561	255.216	75.455

Table 2 Line data of IEEE-14 bus system obtained using proposed technique (IPFC connected in two lines)

Line flow and losses

from Bus	to Bus	*P*/MW	*Q*/Mvar	from Bus	to Bus	*P*/MW	*Q*/Mvar	line loss	
								/MW	/Mvar
1	2	154.297	−16.832	2	1	−150.142	29.518	4.155	12.687
1	5	74.095	7.908	5	1	−71.425	3.114	2.67	11.022
2	3	72.618	6.013	3	2	−70.333	3.613	2.285	9.625
2	4	54.932	2.928	4	2	−53.321	1.958	1.61	4.886
2	5	40.892	4.705	5	2	−40.009	−2.007	0.884	2.698
3	4	−23.341	7.591	4	3	23.737	−6.581	0.396	1.01
4	5	−58.893	11.32	5	4	59.361	−9.846	0.467	1.474
4	7	26.017	−15.163	7	4	−26.017	16.968	0	1.805
4	9	14.943	−2.539	9	4	−14.943	3.744	0	1.205
5	6	44.589	−20.799	6	5	−44.589	26.296	0	5.498
6	11	7.906	9.24	11	6	−7.783	−8.983	0.123	0.257
6	12	7.757	3.339	12	6	−7.68	−3.18	0.077	0.159
6	13	18.015	10.202	13	6	−17.768	−9.714	0.248	0.488
7	8	−0.12	−20.462	8	7	0.12	21.137	0	0.675
7	9	26.403	14.939	9	7	−26.403	−14.013	0	0.926
9	10	3.555	−0.445	10	9	−3.551	0.455	0.004	0.01
9	14	8.573	0.307	14	9	−8.485	−0.119	0.088	0.187
10	11	−4.634	−6.793	11	10	4.686	6.916	0.052	0.123
12	13	1.983	1.313	13	12	−1.972	−1.302	0.011	0.01
13	14	6.522	5.099	14	13	−6.415	−4.881	0.107	0.218
total loss								13.176	54.963

Table 3 Bus data of IEEE-14 bus system obtained using proposed technique (IPFC connected in three lines)

NR load flow analysis

Bus No.	voltage/p.u.	angle/(º)	injection		generation		load	
			/MW	/Mvar	/MW	/Mvar	/MW	/Mvar
1	1.06	0	231.745	–15.186	231.745	–15.186	0	0
2	1.045	–4.9705	18.3	34.792	40	47.492	21.7	12.7
3	1.01	–12.7168	–94.2	8.576	0	27.576	94.2	19
4	1.0135	–10.2043	–47.8	3.9	0	0	47.8	–3.9
5	1.0168	–8.7262	–7.6	–1.6	0	0	7.6	1.6
6	1.07	–14.3786	–11.355	14.767	0	22.241	11.355	7.474
7	1.0464	–13.1589	0.089	0.105	0	0	–0.089	–0.105
8	1.08	–13.1538	0.057	20.615	0	20.624	–0.057	0.009
9	1.0317	–14.7282	–29.326	–16.396	0	0	29.326	16.396
10	1.0313	–14.9405	–8.763	–5.604	0	0	8.763	5.604
11	1.0473	–14.7724	–3.229	–1.389	0	0	3.229	1.389
12	1.0532	–15.2314	–6.211	–1.686	0	0	6.211	1.686
13	1.0469	–15.2649	–13.621	–5.856	0	0	13.621	5.856
14	1.021	–15.9824	–14.603	–4.54	0	0	14.603	4.54
total			13.482	30.497	271.745	102.747	258.263	72.250

Table 4 Line data of IEEE-14 bus system obtained using proposed technique (IPFC connected in three lines)

Line flow and losses

from Bus	to Bus	*P*/MW	*Q*/Mvar	from Bus	to Bus	*P*/MW	*Q*/Mvar	line loss	
								/MW	/Mvar
1	2	156.518	–17.353	2	1	–152.24	30.412	4.277	13.059
1	5	75.227	7.897	5	1	–72.476	3.46	2.751	11.357
2	3	73.272	5.948	3	2	–70.946	3.849	2.325	9.797
2	4	55.719	2.805	4	2	–54.062	2.22	1.656	5.025
2	5	41.55	4.647	5	2	–40.638	–1.863	0.912	2.783
3	4	–23.254	7.614	4	3	23.647	–6.61	0.393	1.004
4	5	–59.415	11.709	5	4	59.892	–10.206	0.477	1.503
4	7	26.728	–15.599	7	4	–26.728	17.506	0	1.907
4	9	15.303	–2.812	9	4	–15.303	4.082	0	1.27
5	6	45.622	–20.775	6	5	–45.622	26.484	0	5.709
6	11	7.902	8.438	11	6	–7.791	–8.206	0.111	0.232
6	12	8.089	3.19	12	6	–8.008	–3.021	0.081	0.169
6	13	18.277	9.801	13	6	–18.028	–9.312	0.248	0.489
7	8	–0.057	–19.973	8	7	0.057	20.615	0	0.642
7	9	26.874	14.35	9	7	–26.874	–13.417	0	0.933
9	10	4.258	–1.08	10	9	–4.252	1.095	0.006	0.015
9	14	8.593	0.141	14	9	–8.505	0.047	0.088	0.188
10	11	–4.511	–6.699	11	10	4.561	6.816	0.05	0.118
12	13	1.797	1.335	13	12	–1.787	–1.326	0.01	0.009
13	14	6.194	4.781	14	13	–6.099	–4.587	0.095	0.194
total loss								13.482	56.405

Table 5 Parameter of lines to be connected in IPFC

number of lines for IPFC connected	bus combination of IPFC connected	voltage deviation/p.u.	voltage angle deviation/(°)
2	4-5	– 0.0455	– 70.5347
	4-7	0.2509	– 136.9757
3	6-11	0.0500	28.0284
	6-12	0.0499	96.0557
	6-13	0.2000	69.0349

Table 6 Loss comparison of TS, GA [25], and without IPFC

number of lines for IPFC connected	total loss/MW		
	TS-NN	GA-NN [25]	without IPFC
2	13.482	13.527	14.755
3	13.176	13.293	

Table 7 Loss comparison of Levenberg-Marquardt back propagation and gradient descent with momentum

number of lines for IPFC connected	total loss/MW	
	TS-NN (Levenberg-Marquardt back propagation)	TS-NN (gradient descent with momentum)
2	13.482	13.3268
3	13.176	13.1703

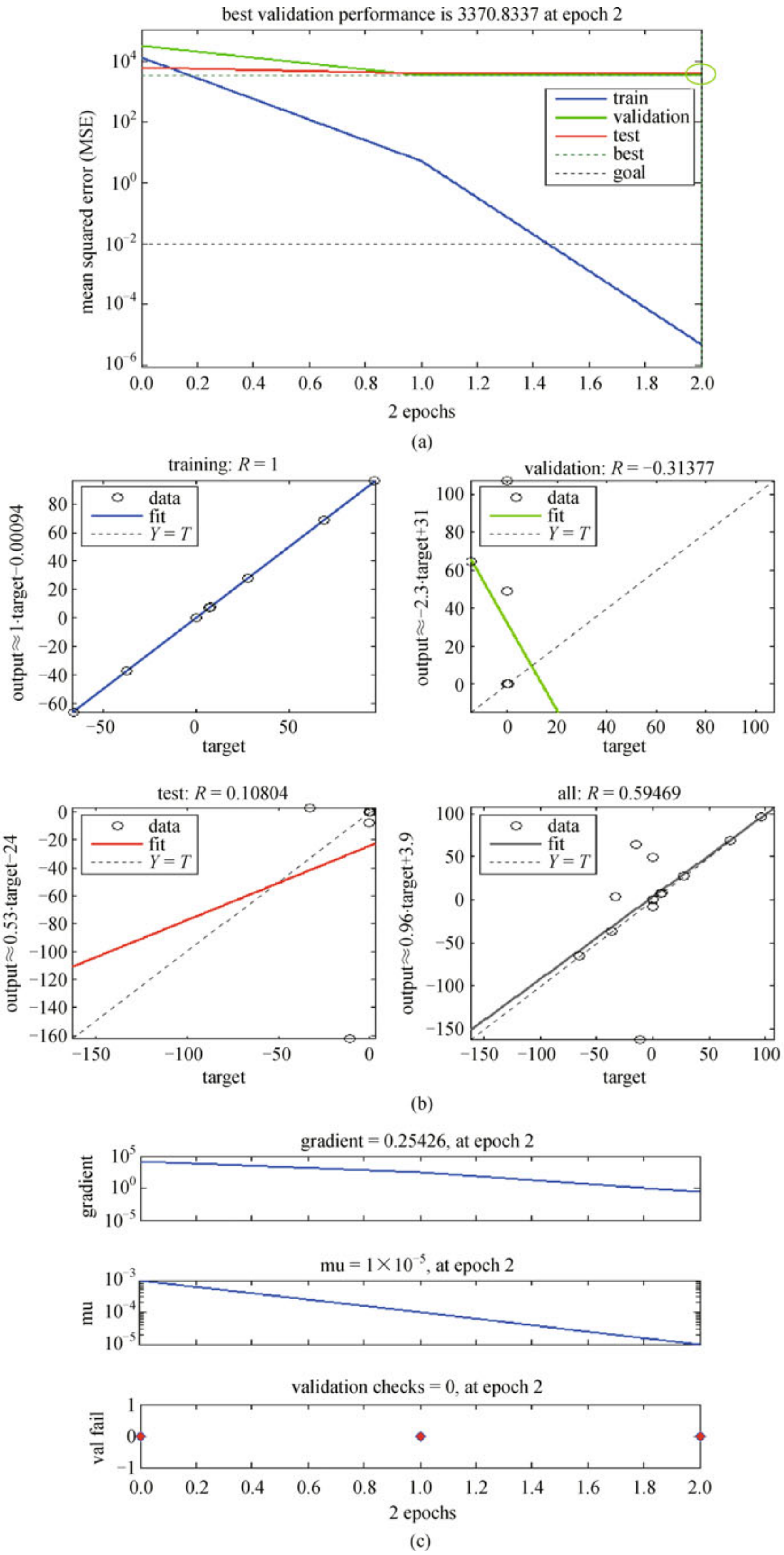
analysis, and the training state of the bus combination and the corresponding bus voltage, real and reactive powers of both the neural networks are shown below. Figures 7(a), 7(b), and 7(c) show the performance, regression, and training graph of the neural network for identification of voltage and angle, and Figs. 8(a), 8(b), and 8(c) show the performance, regression, and training graph of the neural network for identification of buses.

The validation performance is used to validate the training data set in order to identify any mistake. The purpose of regression performance is to check whether the data set is trained correctly or not. The validation set is similar to the training state but it is not equal. Thus, these performances are used to set the network in well-trained stage and to determine the maximum bus combination. From this combination, the optimal location of IPFC is determined based on the real and reactive powers, bus voltage and losses. Then, the losses of the TS algorithm are compared with the GA and without using any IPFC. The comparison performance is described in Fig. 9.

Figure 9 shows that the loss of the TS algorithm is less than that of GA [25] and without IPFC. Also, the complexity of GA is more than that of TS algorithm. However, the introduced TS algorithm is free from the complexity and also the line loss is reduced in both 2 line and 3 line combinations. Therefore, the accuracy of the optimization depends on the procedure of the algorithm. The optimized data set is applied to the network that gives the loss reduced line combinations. Hence, the TS-based hybrid technique is suitable for optimizing better combination of transmission line compared to GA-based hybrid technique.

6 Conclusion

In this paper, an integrated technique for optimizing and controlling the multi transmission line using IPFC was proposed. The proposed technique has utilized a TS-based optimization algorithm to determine the optimum bus combination and an artificial intelligent technique to find out the best location for placing the IPFC. The proposed technique was tested using the IEEE-14 standard bus system. In this standard bus system, the IPFC was connected in line 2 and line 3 of the transmission system. Then, the line losses of the standard bus system were analyzed by means of the general load flow analysis. The obtained results were compared with those obtained by the genetic algorithm, and the compared results have shown that the proposed method has significantly outperformed the other methods in reducing the line losses. Also, the power losses are analyzed with Levenberg-Marquardt back propagation and gradient descent with momentum network training algorithm. The gradient descent with momentum training algorithm based network is identified the best IPFC connecting location compared to Levenberg-

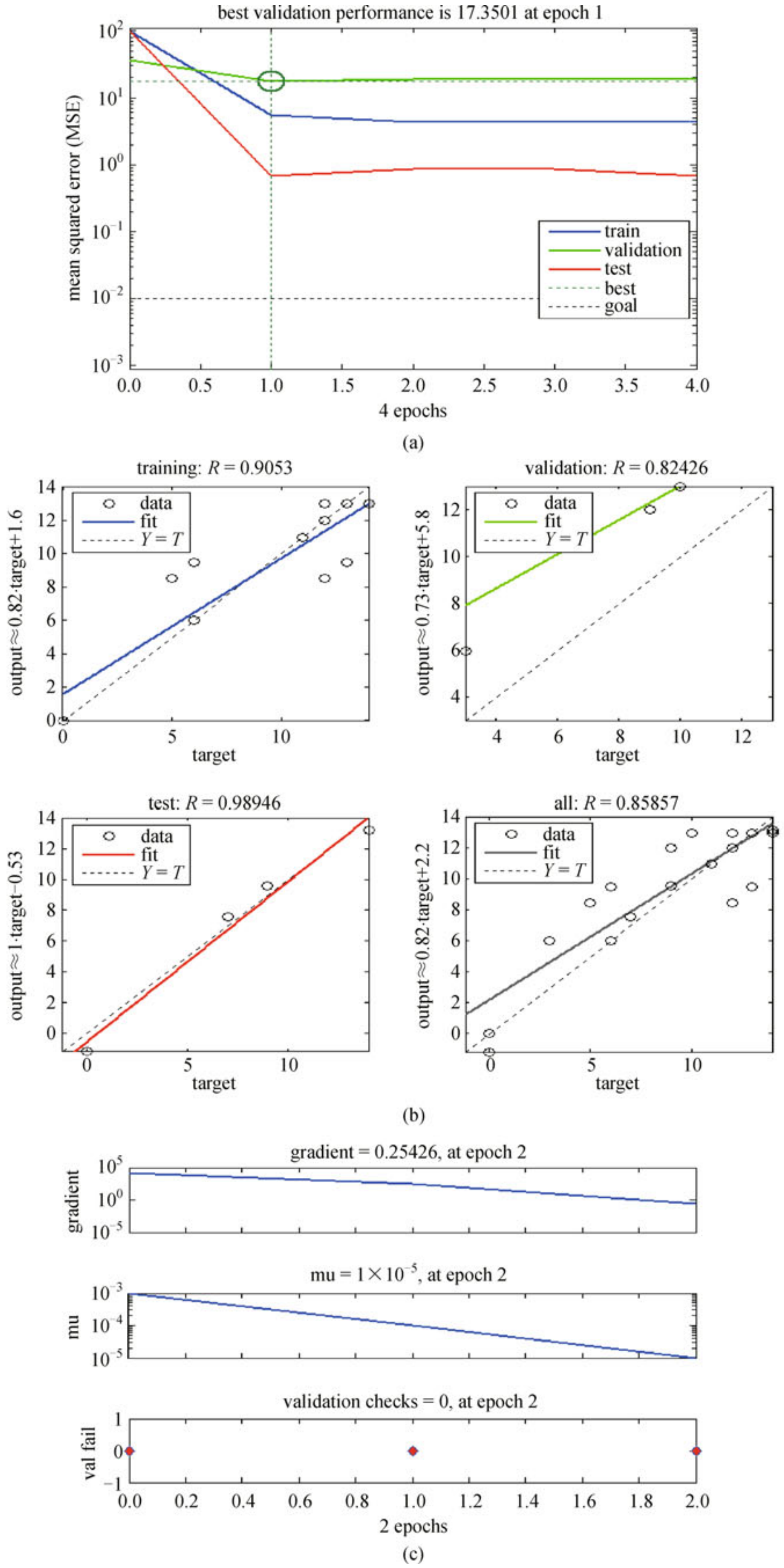


(a)

(b)

(c)

Fig. 7 (a) Performance, (b) regression, and (c) training for identification of voltage and angle



(a)

(b)

(c)

Fig. 8 (a) Performance, (b) regression, and (c) training for identification of buses

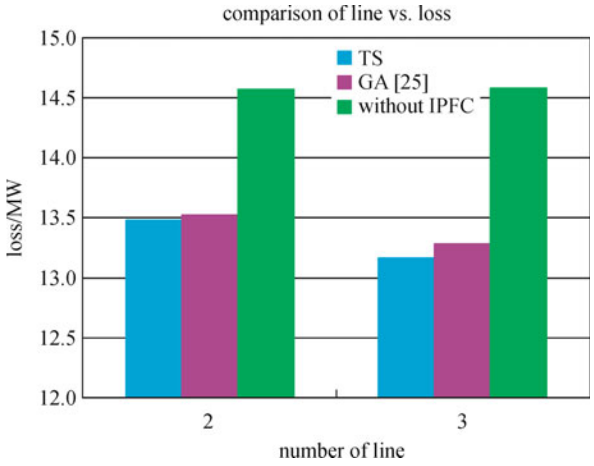


Fig. 9 Performance of loss comparison

Marquardt back propagation.

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