Transmission Usage Allocation in Pool and Bilateral Trades Using Artificial Neural Network

M.W. MUSTAFA, S.N. KHALID, H.SHAREEF, A.KHAIRUDDIN
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
Skudai, 81310, Johor
MALAYSIA
wazir@fke.utm.my, nizam@fke.utm.my, hussain_ln@yahoo.com, azhar@fke.utm.my

Abstract: - This paper proposes methods to allocate transmission usage for pool and bilateral market models in deregulated power industry. This paper focuses on creating an appropriate artificial neural network (ANN) to allocate transmission usage for pool and bilateral trades separately in a simpler and faster manner. The modified IEEE 14-bus network is utilised as a test system to illustrate the effectiveness of the ANN output compared to that of conventional methods used as teachers. The basic idea is to use supervised learning paradigm to train the ANN. Downstream tracing procedure of Graph method is used as a teacher for calculating the contribution factors of individual generator to line flows under pool model. In bilateral model, circuit method is used as a teacher to decouple the line usages on the basis of transactions pairs. The descriptions of inputs and outputs of the training data for the ANN are easily obtained from the load flow results and methods used as teachers respectively. The structure of each ANN is designed to assess the extent of line usage by each generator while supplying to their respective customer. Most commonly used feedforward architecture has been chosen for the proposed ANN based transmission usage allocation technique. Almost all the system variables obtained from load flow solutions are utilised as an input to the neural network. Moreover, tan-sigmoid activation functions are incorporated in the hidden layer to realise the non linear nature of the transmission usage allocation. The proposed ANN based method provides promising results in terms of accuracy and computation time.

Key-Words: - Artificial neural network, Bilateral trades, Graph method, Circuit method, Transmission usage allocation, Power pool.

1 Introduction

The natural monopoly of electric supply industry is being replaced by competitive power markets in the world. This means that once vertically integrated structure operating the whole path from generation to customers are divide into independent parts taking care either about generation, transmission or distribution. In view of market operation it becomes more important to know the role of individual generator making the biggest usage to transmission wires. Transmission usage allocation refers to power contribution of each generator to each line flows. The advantage of knowing the usage allocation includes loss allocation associated to each path, cost assignment to transmission line pricing, congestion management, ancillary services and decision on scheduling generators [1]. Under competitive market, transmission line will be controlled by the independent market operators that would provide equal access right to all interested generating companies. Unlike in the natural monopoly, generating companies will no longer have ownership or handles of transmission facilities. The main role of generating companies would be restricted to selling power. They can operate under a pool or bilateral trades model. At present, power pool is the most common form of market due to its simple structure.

Generating companies and customers both are bid for selling and buying power at the power pool. A power pool conduct different types of auctions likes day ahead market, hour ahead market, real time market and spot market to buy and sell electric power from the market. Recent trends in the bulk power consumer have been towards into bilateral transactions service with electric power utilities to avoid price fluctuations of energy market in a deregulated environment. Electric power utilities need to know the actual cost of providing unbundled services in order to make correct economic decisions that they should promote or curtail while considering their service obligations. As part of these trends, the emphasis on the knowledge of providing unbundled transmission service has been important and increase steadily. The concept of bilateral transactions allows the consumers and utilities to work according to their policy and does not make them dependent on everyday bid like in a pool model. Bilateral transactions enable consumers to make their best price deals for generation supply with whoever in the competitive market is most effective to meet their load demand. Allowing supplier to transact directly with consumers creates competition in terms of pricing, contract duration, payment terms, type of generation and type of electric service on both sides of the transaction. Generating companies compete among themselves to supply this demand. This gives consumers a full range of choices among generator. Thus, bilateral transactions will provide a wide range of choices to meet various customer needs.

Typically, the transactions are executed through independent market operators or independent system operators. Therefore, each supplier has to produce enough power to meets its transacted powers with individual customers and system losses. One of the most crucial 'technical' data needed about a transaction is the actual usage and path of the power follow from each generator or load across the interconnected system. For that reason it is vital to determine the impact and flow path of the simultaneous transaction taking place in the system accurately and efficiently [2]. This knowledge of the transmission usage is also essentially important in the implementation of usage-based cost allocation methods. Due to non-linear nature of power flow, it is difficult to decouple the actual line flows into components associated with individual transaction pairs accurately. Therefore it is required to use various techniques such as circuit concepts, tracing algorithms or sensitivity indices to estimate the contribution to actual line flows from individual customers.

The tracing methods [3-6], based on the actual power flows in the network and the proportional sharing principles, are effectively used in transmission usage allocation; but it is only suitable for pool based market model. Reference [7] proposed a modification of tracing method in [3]. The method, based on proportionality concepts, traces the decomposition of flows from generators and loads simultaneously by using Markov chains. However the matrix calculation is more complex and the speed is a problem for a big network. The method reported in [8] is based on tracing the current and complex power from individual power sources to system loads. Based on solved load flow, the method converts power injections and line flows into real and imaginary current injections and current flows. This method, while offering a clear physical meaning and unique results, however is time consuming.

In [9], line power flows are first unbundled into a sum of components, each corresponding to a bilateral transaction. The scheme then proposes ways in which the coupling terms among the components appearing in the line losses can be allocated to individual bilateral transactions. Reference [10] proposed a distributed slack bus scheme for transmission and ancillary services pricing associated to bilateral transaction market. A circuit approach to allocate transmission losses for simultaneous bilateral transaction is proposed in [11-12].

Reference [13] proposed a systematic method based on the basic circuit theories, equivalent current injection and equivalent impedance to allocate the power flow and loss for deregulated transmission system. However arranging payments with counter flows is a difficult process. The method to allocate the power flow and losses based on the electric circuit theories is proposed in [14]. This method assumed that the current at each network injection point may flow through all lines and reach all loads, which may not be true for all system. Reference [15] introduced the transaction pairs based on circuit concept to calculate associated losses for bilateral transactions in an interconnected system. However this method does not demonstrate the application of line usage allocation.

In the novel MW-mile formulation as well as some usage-based allocation-pricing rules, impact of each transaction on the flows is measured by the magnitude so that all transmission users are required to pay for the use of path-provision service, irrespective of the flow directions. However, in view of the contributions of counter flows in relieving the congested transmission lines, any usage-based tariff that charges for counter flows need to be carefully reviewed [16].

In [17], sensitivity factors are proposed for pricing transmission costs which depend on a base load flow case. However, it can be inaccurate for a large transaction, thus additional corrective scheme need be considered. Reference [18] proposed the actual use of transmission facilities, by using product of power due to a particular transaction times the distance travels in the network. In a related work based on artificial intelligent techniques, [19] proposed a transmission loss allocation method using ANN. The ANN allocates losses with good accuracy and in a quick manner. From the extensive literature review it can be seen that the proposed methodology is still unique and not being applied directly to the determination of the line usage allocation. The goal of this research is to incorporate the ANN to calculate line usage associated to pool and bilateral transactions between purchasing and selling entities. Method based on Graph theory [4] has been chosen as a teacher to train the neural network in pool model while a Circuit theory method [15] is used for bilateral model. Artificial intelligence has been proven to be able to solve complex processes in deregulated power system such as loss allocation. So, it can be expected that the developed methodology will further contribute in improving the computation time of transmission usage allocation for deregulated system. A short description of each conventional method will be described next as it has been used as teachers of developed ANN methodology.

2 Graph Method for Pool Trade

The method assumes that a generator has the priority to provide power to the load on the same bus and is based on the following lemmas of graph theory.

Lemma 1: A lossless, finite-nodes power system without loop flow has at least one pure source, i.e. a generator bus with all incident lines carrying outflows.

Lemma 2: A lossless, finite-nodes power system without loop flow has at least one pure sink, i.e. a load bus with all incident lines carrying inflows.

Based on these two lemmas downstream tracing sequence briefly described the method. The downstream tracing (DSTR) is used for calculating the contribution factors of individual generators to line flows and loads. This process initially requires the formation of intermediate matrices called extraction factor matrix of lines, A_l and loads A_L from total passing power of their upstream buses i.e. $P_l = A_l.P$ and $P_L = A_L.P$ respectively. Where P_l and P_L are the vector of line and load power respectively. P is a vector of bus total passing power in the bus sequence of downstream tracing. Then the nonzero elements in A_l and A_L are calculated with the following equations.

$$(A_l)_{line\ j, bus\ i} = \frac{line\ j's\ power\ flow}{bus\ i's\ total\ pass\ power\ P_i} \tag{1}$$

$$A_{L_{ii}} = \begin{cases} 0 & i \notin net\ load\ buses \\ \dfrac{net\ load\ power\ on\ bus\ i}{P_i} & i \in net\ load\ buses \end{cases} \tag{2}$$

The next step involves the calculation of contribution factor matrix B of generators to bus total passing power. Mathematically this can be expressed as $P = B.P_G$. The elements of B are calculated using the equation given below.

$$B = B_{bus-i,bus-k} \begin{cases} 1 & (k = i, k \in net\ gen.buses) \\ 0 & (k = i, k \notin net\ gen.buses) \\ 0 & (k > i) \\ 0 & (k < i, k \notin net\ gen.buses) \\ \sum_{l_{j \in i}} \left(A_{lj-m} \cdot B_{m-k}\right) & (k < i, k \in net\ gen.buses) \end{cases} \tag{3}$$

where $k < i$ means k is an upstream bus of bus i, and $k > i$ means k is a downstream bus of bus i. The last expression is for the lower triangular nonzero elements. The term $l_{j \in i}$ means line j is an inflow line of bus i. $A_{l_{j-m}}$ is the unique nonzero element corresponding to line j in matrix A_l with bus m as its upstream terminal. B_{m-k} is the element in matrix B already calculated which represents the contribution of generator k to the total injection power of bus. By substituting $P = B.P_G$ in $P_l = A_l.P$ and $P_L = A_L.P$ contribution of each generator to line flows and loads can be calculated. Exact derivation can be found on [4]. Vector P_l is used as a target in the training process of the proposed ANN.

3 Circuit Method for Bilateral Trade

Transaction pair encompasses of a sending bus and associated receiving bus. Each transaction pair corresponds to a bilateral energy transaction. An ideal transaction pair is self-balancing, i.e., its net real generation should be equal to the sum of its active demand and associated transmission loss. The method assumes that each sending bus, is only associated with a single or multiple transactions. The following notations are used in this paper.

ns : Set of sending buses in the system;
nb : Set of sinking buses in the system;
nl : Set of all branches in the system;
nt : Set of bilateral transactions in the system;
T_k : k^{th} bilateral transaction (transaction pairs);
V_i: Complex voltage value at bus i, $V_i = V_i e^{j\theta_i}$
I_i , $I_{branch(ij)}$: Complex injected current value and branch current value of bus i and branch (ij).
$S_i = P_i + jQ_i$: Net complex power in term of bus i
$y_{ij} = g_{ij} - jb_{ij}$: The admittance of the branch (ij);

Based on net real power generation, it should be equal to the sum of its active demand and associated transmission loss to form a transaction balance equations [15].

For each $T_k \in nt$;

$$\begin{cases} P_k = \sum P_m + P_{loss}^{(T_k)}, k \in T_k \cap ns \text{ and } m \in T_k \cap nb \\ P_{Loss}^{(Tk)} - \text{ transaction loss of } T_k; \end{cases} \quad (4)$$

All power injections are translated into complex injected currents to bypass non-linear coupling between real and reactive power flow equations as follows:

$$I_i = \frac{S_i^*}{V_i^*} = \frac{P_i - jQ_i}{V_i e^{-j\theta_i}}, i \in ns \text{ or } I_i = \frac{-S_i^*}{V_i^*} = \frac{-P_i + jQ_i}{V_i e^{-j\theta_i}}, i \in nb \quad (5)$$

Complex branch current components imposed by individual transaction can be calculated using the equation given below.

For each $T_k \in nt, \text{ and } k \in ns \cap T_k, m \in nb \cap T_k$

$$I_{branch(ij)}^{Tk} = y_{ij} \times \left\{ \frac{P_k - jQ_k}{V_k e^{-j\theta_k}} \left(Z_{ik} - Z_{jk} \right) + \sum_{m \in Tk \cap nb} \frac{-P_m + jQ_m}{V_m e^{-j\theta_m}} \left(Z_{im} - Z_{jm} \right) \right\} \quad (6)$$

where

y_{ij} – the admittance of the branch (ij);

Z_{ik}, et al – means ik^{th} entries of the nodal impedance matrix

Notice that the decoupled branch current vectors are exact solutions from Kirchoff Laws. Accordingly, both real and reactive losses $P_{Loss}^{(Tk)}$ and $Q_{Loss}^{(Tk)}$ incurred by T_k can be calculated by,

$$P_{Loss}^{(Tk)} = \sum_{ij \in nl} P_{Loss(ij)}^{(Tk)} = \sum_{ij \in nl} Re\left\{ I_{branch(ij)}^{(Tk)} \times (V_i^* - V_j^*) \right\}$$

$$Q_{Loss}^{(Tk)} = \sum_{ij \in nl} Q_{Loss(ij)}^{(Tk)} = -\sum_{ij \in nl} Im\left\{ I_{branch(ij)}^{(Tk)} \times (V_i^* - V_j^*) \right\} \quad (7)$$

Substituting $P_{Loss}^{(Tk)}$ from (7) into (4), it is possible to get expanded power flow equation which can be solved using Newton-Raphson method until transaction balance is reached. Once the transaction balance is obtained, real power flow components (denoted by $P_{branch(ij)}^{(Tk)}$) in branch (ij) contributed by a transaction T_k can be identified by,

$$P_{branch(ij)}^{(Tk)} = Re\left\{ I_{branch(ij)}^{(Tk)} \times V_i^* \right\} \quad (8)$$

Finally, the actual real power flow in branch between bus i and j can be represented in terms of transaction pairs as,

$$P_{branch(ij)} = \sum_{k=1}^{nt} P_{branch(ij)}^{(Tk)} \quad (9)$$

The proposed usage allocation technique is applicable for all general networks. Vector $P_{branch(ij)}^{(Tk)}$ is used as a target in the training process of the proposed ANN.

4 Neural Network Architecture

An ANN can be defined as a data processing system consisting of a large number of simple, highly interconnected processing elements (artificial neurons) in an architecture inspired by the structure of the cerebral cortex of the brain [17]. The processing elements consist of two parts. The first part simply sums the weighted inputs; the second part is effectively a nonlinear filter, usually called the activation function, through which the combined signal flow. These processing elements are usually organised into a sequence of layers or slabs with full or random connections between the layers. Neural network perform two major functions which are training (learning) and testing (recall). Testing is an integral part of the training process since a desired response to the network must be compared to the actual output to create an error function.

5 Structure of the Proposed ANN in Pool and Bilateral Trade

One of the main objectives of this work is to incorporate ANN into line usage allocation for pool and bilateral trades. The structure of the proposed neural network for each power system model is discussed in the following sub-sections.

5.1 Pool Trade

Five fully connected feedforward neural networks under MATLAB platform are utilised to obtain line usage allocation results for the modified IEEE 14-bus system as shown in Fig.1. Each network corresponds to a single contributing generator to the line flows and each consists of one hidden layer and a single output layer. This realisation is adopted for simplicity and to reduce the training time of the neural networks.

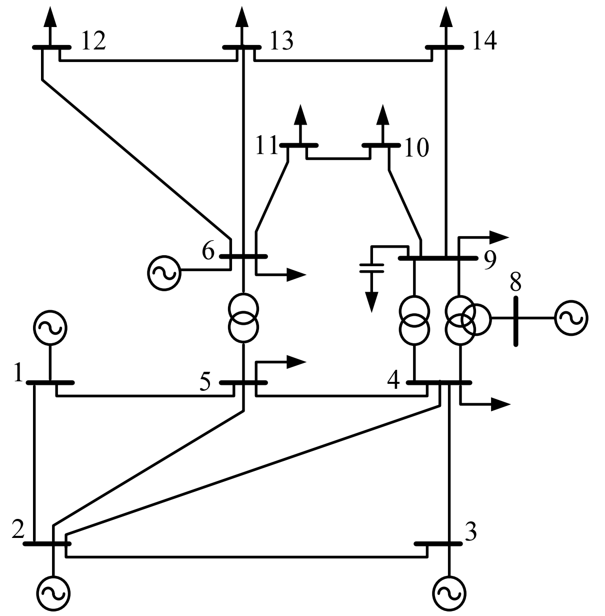

Fig.1: Single line diagram for the modified IEEE 14-bus system

This system consists of 5 generators located at buses 1, 2, 3, 6, and 8 respectively. They deliver power to 9 loads, through 20 lines located at buses 4, 5, 7, 9 to 14 respectively.

The input samples for training is assembled using the daily load curve and performing load flow analysis for every hour of load demand. Similarly the target vector for the training is obtained from the Graph method [4]. Input data (D) for developed ANN contains independent variables such as real power generation *(P_{g1}, P_{g2}, P_{g3}, P_{g6}, and P_{g8})*, real power demand *(P_4, P_5, P_7, P_9 to P_{14})*, bus voltage magnitude (V_4, V_5, V_7, V_9 *to* V_{14}), real power for line flows *(P_{line1} to P_{line20}* and the target/output parameter, (T) contains generator contribution to all line flows which corresponds to 20 output neurons. Table 1 summarises the description of inputs and outputs of the training data for each ANN.

Table 1: Description of Inputs and Outputs of the Training Data for Each ANN

Input and Output (layer)	Neurons	Description in (p.u)
I_1 to I_5	5	Real power generations
I_6 to I_{14}	9	Real power demand
I_{15} to I_{23}	9	Bus voltage magnitude
I_{24} to I_{43}	20	Real power for line flows
O_1 to O_{20}	20	Real power flow in line

5.2 Bilateral Trade

In this case study, structure and description of input and output of each ANN is similar to those of the pool based market. The five simultaneous bilateral transactions are obtained by allowing five generators to transact directly with five bundled consumer groups. Table 2 shows the details of transaction pairs between market participants for the modified IEEE 14-bus system.

Table 2: Transaction pairs for the modified IEEE 14-Bus System

Transaction Pairs		From generator	To load
T1	$P^{g1}_{d4,9,13,14}$	1	4,9,13,14
T2	$P^{g2}_{d7,12}$	2	7,12
T3	$P^{g2}_{d7,12}$	3	5
T4	P^{g6}_{d11}	6	11
T5	P^{g8}_{d10}	8	10

For the purpose of ANN based method, target vectors that resembles the line usage of each transacting generator is obtained using the method discussed in Section 3.

5.3 Training

Neural networks are sensitive to the number of neurons in their hidden layer. Too few neurons in the hidden layer prevent it from correctly mapping inputs to outputs, while too many may impede generalisation and increasing training time. Therefore number of hidden neurons is selected through experimentation to find the optimum number of neurons for a predefined minimum of mean square error and compromise with the lowest number of epochs in each training process. To take into account the nonlinear characteristic of input (D) and noting that the target values are either positive or negative, the suitable transfer function to be used in the hidden layer is a tan-sigmoid function. Non linear activation functions allow the network to learn nonlinear relationships between input and output vectors. Levenberg-Marquardt algorithm has been used for training the network. After the input and target for training data is created, next step is to divide the data (D and T) up into training, validation and test subsets. In this case 14 samples (60%) of data are used for the training and 5 samples (20%) of each data for validation and testing. Table 3 shows the numbers of samples for training, validation and test data. The error on the training set is driven to a very small value. If the calculated output error becomes much larger than acceptable, when a new data is presented to the trained network, then it can be said that the network has memorised the training samples, but it has not learned to generalise to new situations.

Table 3: The Numbers of Samples for Training, Validation and Test Set

Data Types	Samples (Hour)
Training	1,6,11,16,21,3,8,13,18,23,5,10,15,20
Validation	2,7,12,17,22
Testing	4,9,14,19,24

Validation sets is used to avoid this overfitting problem. The test set provides an independent measure of how well the network can perform on data not used to train it. Fig.2 shows the performance of the training for the ANN with 59 hidden neurons under pool trade. From Fig.2, it can also be seen that the training goal is achieved in 5 epochs with a mean square error of 1.07384×10^{-14}. Here again the performance of the training for the ANN with 59 hidden under bilateral trade is shown in Fig.3. The training goal is also achieved in 5 epochs with a mean square error of 4.9574×10^{-15}. Note that the mean square error of bilateral trade is much smaller than pool trade. This indicates that the developed ANN under bilateral trade can allocate real power transfer between generators and line flows with higher accuracy than pool trade. The results of each training for the ANN is reasonable, since the test set error and the validation set error have similar characteristics, and it doesn't appear that any significant overfitting has occurred. The same network setting parameters is used for training the other 4 networks of each method.

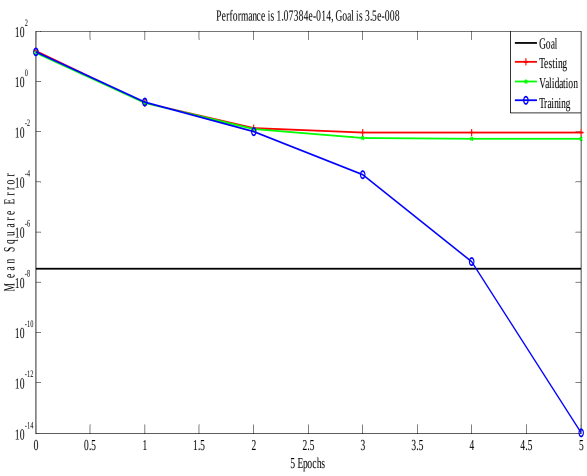

Fig.2: Training, validation and test curve with 59 hidden neurons under pool trade

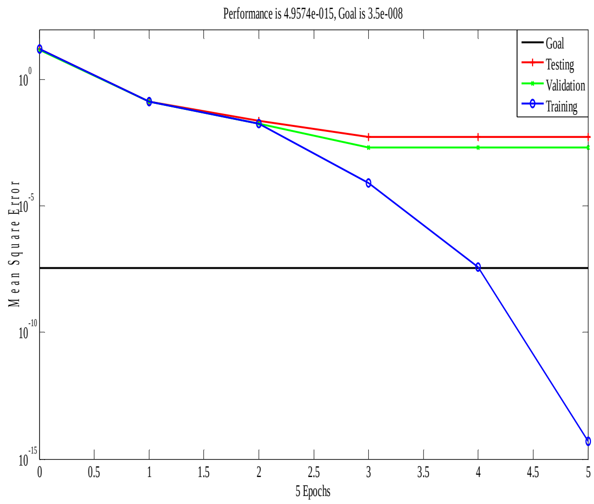

Fig.3: Training, validation and test curve with 59 hidden neurons under bilateral trade

5.4 Pre-testing and simulation

After the networks have been trained, next step is to simulate the network. The entire sample data is used in pre testing. After simulation, the obtained result from the trained network is evaluated with a linear regression analysis. In pool trade, the regression analysis for the trained network that referred to contribution of generator at bus 3 to line flow (P_{4-7}) is shown in Fig.4. The correlation coefficient, (R) in this case is equal to one which indicates perfect correlation between conventional method and output of the neural network. The best linear fit is indicated by a solid line whereas the perfect fit is indicated by the dashed line. Next, similar results is obtained on regression analysis under bilateral trade for the trained network that referred to contribution of generator at bus 2 to line flow (P_{2-4}) as shown in Fig.5. Daily load curves for every load bus and the target patterns for each trade are given in Appendix.

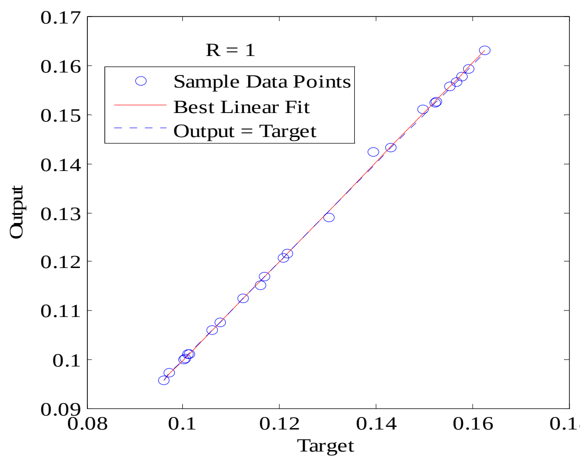

Fig.4: Regression analysis between the network output and the corresponding target under pool trade

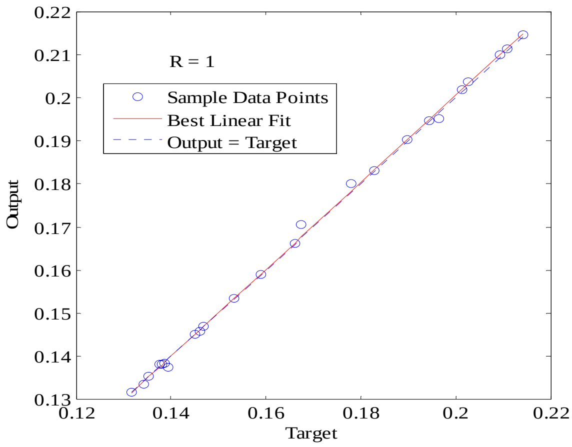

Fig.5: Regression analysis between the network output and the corresponding target under bilateral trade

6 Result and Analysis

A number of simulations have been carried out to demonstrate the accuracy of the developed ANN. The case scenario under pool trade is that, for each hour the real and reactive power at each load is assumed to decrement by 10% from hour 1 to 24, from the nominal trained pattern. Fig.6 shows the line usage allocation result for generator located at bus 2 calculated by the ANN along with the result obtained through to Graph method for line flows P_{6-11}, P_{6-12}, P_{9-10}, P_{9-14}, P_{10-11}, P_{12-13}, and P_{13-14} within 24 hours. Results obtained from ANN are indicated with lines having circles and the solid lines represent the output of the graph method. From Fig. 6, it can be observed that the developed ANN can allocate line usage to generator involved in pool trade with very good accuracy, at almost 97%. In this simulation, ANN computes within 75 msec whereas the Graph method took 1000 msec for the calculation of the same line usage allocation. Therefore it can be concluded that the ANN is more efficient in terms of computation time.

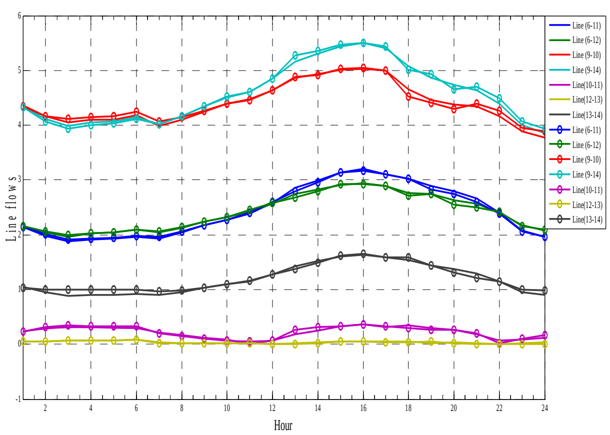

Fig.6: Line usage allocation result for generator 2 within 24 hours

Moreover, the final allocation of real power to line flows using proposed ANN on hour 9 out of 24 hours is presented in Table 4 along with the result obtained through Graph method in Table 5. It can be observed that the sum of the line flows contributed by each generator obtained from Graph method is in conformity with the actual power flow.

Table 4: Analysis of Line Usage Allocation on Hour 9 by the ANN for the Pool Trade Model

Line flows From-To		Actual flow (MW)	ANN Output Gen-1 (MW)	Gen-2 (MW)	Gen-3 (MW)	Gen-6 (MW)	Gen-8 (MW)	Total Flow (MW)
1	2	114.820	114.83	0	0	0	0	114.830
1	5	78.871	78.793	0	0	0	0	78.793
2	3	21.808	15.783	5.894	0	0	0	21.677
2	4	70.429	51.160	19.119	0	0	0	70.279
2	5	62.234	45.463	16.937	0	0	0	62.400
3	4	49.943	15.762	5.867	28.563	0	0	50.192
4	5	-35.17	-30.890	-4.242	0	0	0	-35.132
4	7	56.368	35.469	10.565	10.197	0	0	56.231
4	9	35.682	22.645	6.653	6.471	0	0	35.769
5	6	73.076	64.522	8.775	0	0	0	73.297
6	11	24.281	15.878	2.178	0	6.287	0	24.343
6	12	24.926	16.265	2.236	0	6.395	0	24.896
6	13	48.853	31.939	4.372	0	12.55	0	48.861
7	8	-39.910	0	0	0	0	-36.708	-36.708
7	9	78.625	28.897	8.578	8.261	0	32.786	78.522
9	10	31.751	14.366	4.260	4.129	0	9.087	31.842
9	14	32.407	14.598	4.340	4.161	0	9.295	32.394
10	11	0.827	0.260	0.095	0.105	0	0.228	0.688
12	13	-0.189	-0.107	-0.014	0	-0.044	0	-0.165
13	14	11.536	7.610	1.038	0	2.930	0	11.579

Note that the result obtained by the proposed ANN in this paper is also compared well with the result of actual power flow in Table 4. The total line flows from the proposed method are evaluated by summing each of line flows due to individual generators contribution. The difference of total line flows of the proposed method with the actual flow is small which are less than or equal to 3.2105 MW. From Table 5, it can be shown that the sum of individual generator contribution to line flow is equal to actual line loading and follows the same sign as calculated through load flow program. For this reason the acquired result determined by Graph method illustrates that the counter flow does not exist. In case scenario under bilateral trade, similarly 10% decrease in load pattern is realised. The line usage allocation results referred to transaction pairs (T1) for line flows P_{3-4}, P_{6-11}, P_{6-12},

$P_{6\text{-}13}$, $P_{7\text{-}8}$, $P_{10\text{-}11}$, and $P_{12\text{-}13}$ within 24 hours is shown in Fig.7.

Table 5: Analysis of Line Usage Allocation on Hour 9 by the Graph Method for the Pool Trade Model

Line flows From-To		Actual flow (MW)	Graph Method Gen-1 (MW)	Gen-2 (MW)	Gen-3 (MW)	Gen-6 (MW)	Gen-8 (MW)
1	2	114.820	114.820	0	0	0	0
1	5	78.871	78.871	0	0	0	0
2	3	21.808	15.877	5.930	0	0	0
2	4	70.429	51.275	19.154	0	0	0
2	5	62.234	45.309	16.925	0	0	0
3	4	49.943	15.714	5.869	28.359	0	0
4	5	-35.17	-30.940	-4.235	0	0	0
4	7	56.368	35.603	10.560	10.204	0	0
4	9	35.682	22.538	6.684	6.459	0	0
5	6	73.076	64.277	8.798	0	0	0
6	11	24.281	15.915	2.178	0	6.188	0
6	12	24.926	16.337	2.236	0	6.353	0
6	13	48.853	32.019	4.383	0	12.451	0
7	8	-39.910	0	0	0	0	-39.920
7	9	78.625	29.072	8.623	8.332	0	32.598
9	10	31.751	14.336	4.252	4.108	0	9.055
9	14	32.407	14.632	4.340	4.193	0	9.242
10	11	0.827	0.373	0.110	0.107	0	0.236
12	13	-0.189	-0.124	-0.017	0	-0.048	0
13	14	11.536	7.561	1.035	0	2.940	0

Similar to previous case, results obtained from the ANN are indicated with line having circles and the solid lines represent the output of the Circuit method. In this case, the results show that the developed ANN can allocate real power transfer between generators and line flows with improved accuracy, 1% higher compared to case scenario under pool trade.

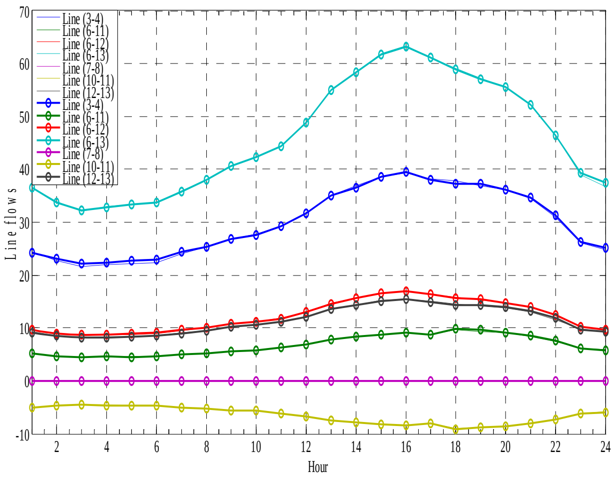

Fig.7: Line usage allocation result for $P^{g1}_{d4,9,13,14}$ within 24 hours

From Fig.7, it can be seen that the generator 1 making more usage of line flow $P_{6\text{-}13}$. For this 24 hours (samples) simulation, ANN computes the output within 16 msec whereas the Circuit method took 5765 msec for the same simultaneous bilateral trades (T1).

Table 6: Bus data for the modified IEEE 14-bus system on hour 9

Bus no.	Voltage Magnitud (p.u)	Voltage Angle (p.u)	Generation Real (MW)	Generation Reactive (Mvar)	Load Real (MW)	Load Reactive (Mvar)
1	1.045	0	193.69	32.762	0	0
2	1.02	-3.55	42.01	23.028	0	0
3	1.02	-6.049	28.359	23.332	0	0
4	0.953	-10.22	0	0	58.604	5.951
5	0.956	-9.248	0	0	26.852	7.661
6	0.9	-21.60	24.991	8.065	0	0
7	0.9463	-17.73	0	0	17.658	3.181
8	1.03	-13.60	39.923	50.38	0	0
9	0.905	-23.53	0	0	50.139	14.193
10	0.885	-25.23	0	0	30.496	3.078
11	0.872	-25.01	0	0	24.381	5.643
12	0.848	-25.74	0	0	24.098	5.472
13	0.850	-25.818	0	0	35.073	7.866
14	0.833	-29.23	0	0	41.837	4.446

The bus data for the modified IEEE 14-bus system on hour 9 is given in Table 6 which represents load demand and generation involved in bilateral trades. The final allocation of real power to line flows using proposed ANN on this hour is presented in Table 7 along with the result obtained through Circuit method as given in Table 8.

As expected, the sum of the real power allocation to line flows obtained from Circuit method is in conformity with the actual power flow. Note that the result obtained by the ANN output is compared well with the result of Circuit method. The total line flows from the proposed method are evaluated by summing each of decouple line flows due to transaction pairs.

The difference of total line flows of the proposed method with the actual flow is small which are less than or equal to 0.3951 MW.

A close look at the both test system shows the ANN output compares well to that of the actual power flows (target). Note that, in Table 6 there are some transactions that creates counter flows in some lines.

For example, transaction pairs (T1) produces opposite flows in line P_{9-10}, P_{10-11}, and P_{12-13}. This helps to improve the line capacity use in the system.

Table 7: Analysis of Line Usage Allocation on Hour 9 by the ANN for the Bilateral Trade Model

Line		Actual	ANN Output (Transaction Pairs)					Total
flows		flow	T1	T2	T3	T4	T5	Flow
From-		(MW)	(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
1	2	114.820	126.700	-7.900	-3.450	0.166	-0.260	115.20
1	5	78.871	66.200	7.917	3.707	-0.14	1.012	78.69
2	3	21.808	26.510	6.641	-11.300	0.147	-0.310	21.63
2	4	70.429	54.250	13.950	1.834	0.333	-0.220	70.14
2	5	62.234	42.550	13.380	6.057	-0.300	0.471	62.15
3	4	49.943	26.860	6.819	16.510	0.149	-0.450	49.88
4	5	-35.17	-50.000	-2.980	16.790	-2.790	3.897	-35.10
4	7	56.368	44.950	16.780	0.587	2.086	-8.330	56.07
4	9	35.682	25.780	6.285	0.341	1.183	1.931	35.52
5	6	73.076	55.740	18.13	-0.910	-3.27	3.267	72.94
6	11	24.281	5.616	-2.690	-0.580	18.41	3.394	24.15
6	12	24.926	10.790	14.060	-0.070	0.578	-0.340	25.00
6	13	48.853	40.590	7.448	-0.290	2.122	-1.030	48.83
7	8	-39.920	0	0	0	0	-39.90	-39.90
7	9	78.625	47.570	-0.110	0.620	2.301	28.300	78.68
9	10	31.751	-5.670	2.677	0.589	6.322	27.910	31.82
9	14	32.407	29.670	3.628	0.384	-2.670	1.476	32.48
10	11	0.8265	-5.580	2.669	0.572	6.279	-3.120	0.807
12	13	-0.189	10.170	-10.500	-0.070	0.520	-0.350	-0.32
13	14	11.536	14.280	-3.450	-0.360	2.579	-1.470	11.57

Table 8: Analysis of Line Usage Allocation on Hour 9 by the Circuit Method for the Bilateral Trade Model

Line		Actual	Circuit Method (Transaction Pairs)				
flows		flow	T1	T2	T3	T4	T5
From-To		(MW)	(MW)	(MW)	(MW)	(MW)	(MW)
1	2	114.820	126.300	-7.920	-3.460	0.162	-0.260
1	5	78.871	66.390	7.918	3.703	-0.140	1.001
2	3	21.808	26.650	6.665	-11.300	0.151	-0.310
2	4	70.429	54.510	13.970	1.833	0.332	-0.220
2	5	62.234	42.690	13.380	5.997	-0.300	0.474
3	4	49.943	26.860	6.812	16.570	0.157	-0.450
4	5	-35.170	-50.000	-3.040	16.80	-2.79	3.905
4	7	56.368	45.060	17.030	0.590	2.078	-8.390
4	9	35.682	25.850	6.366	0.338	1.192	1.935
5	6	73.076	55.850	18.140	-0.920	-3.280	3.294
6	11	24.281	5.627	-2.650	-0.570	18.500	3.389
6	12	24.926	10.78	14.020	-0.070	0.559	-0.340
6	13	48.853	40.610	7.452	-0.290	2.139	-1.040
7	8	-39.920	0	0	0	0	-39.900
7	9	78.625	47.590	-0.110	0.622	2.287	28.240
9	10	31.751	-5.680	2.697	0.584	6.387	27.770
9	14	32.407	29.620	3.655	0.382	-2.720	1.479
10	11	0.8265	-5.580	2.659	0.576	6.313	-3.130
12	13	-0.189	10.220	-10.500	-0.070	0.526	-0.350
13	14	11.536	14.260	-3.450	-0.360	2.572	-1.470

7 Conclusion

This paper proposes an artificial intelligence technique to allocate transmission usage for pool and simultaneous bilateral trades independently. The developed ANN adopts line usage allocation outputs determined by each conventional method respectively as a teacher to train the neural networks. The proposed ANN based method provides the results in a faster and convenient manner with very good accuracy. Adaptation of appropriate ANN architectures for the large real life test system is expected to deliver a considerable efficiency in computation time especially during training processes. Moreover the training process should be carried out for every change in the system configuration. Accordingly, the proposed method has been successfully tested and demonstrated on the modified IEEE 14-bus system. In future the proposed method could be adapted to real time application of transmission usage allocation for both bilateral and pool trade power market. Incorporating optimisation techniques into the allocation scheme is currently under investigation and the results will be reported in the future.

8 Appendix

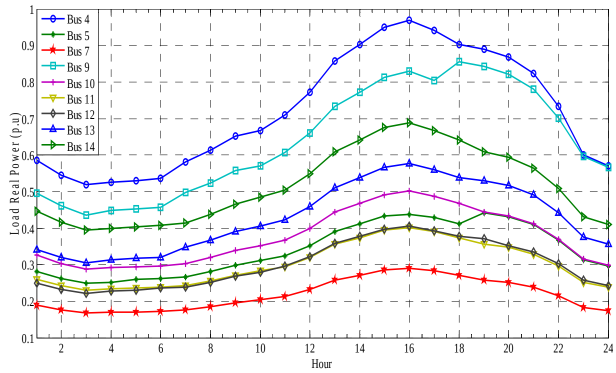

Fig.8: Daily load curves for different buses under pool and bilateral trade

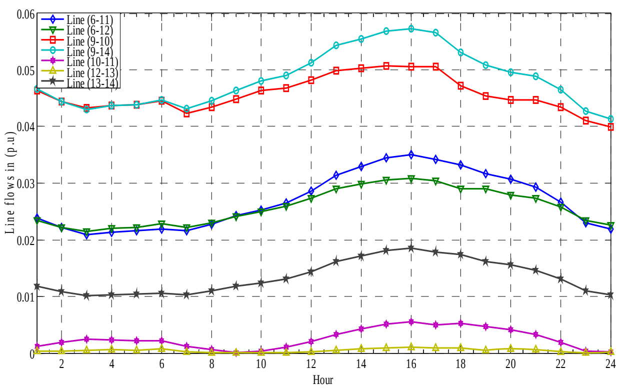

Fig.9: Selected target patterns of generator at bus 2 under pool trade within 24 hours

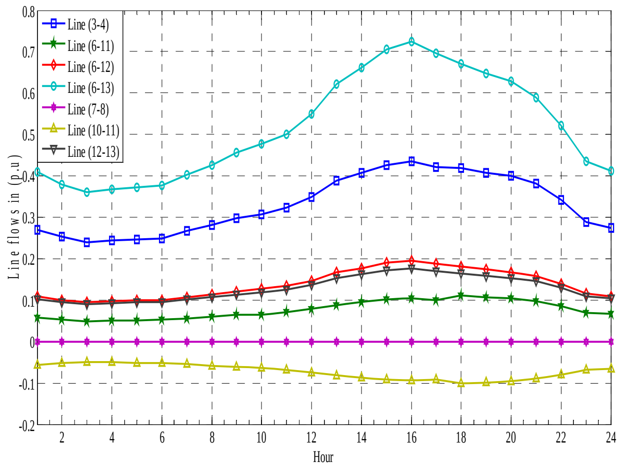

Fig.10: Selected target patterns of generator at bus 1 under bilateral trade (T1) within 24 hours

References:

[1] L. Valerie, K.S. Tapan and T. Downs, Preliminary findings on usage allocation and loss allocation of electricity in deregulated market, *in Proc. AUPEC 2003 Australasian Universities Power Engineering Conf,* 2003.

[2] K.Visakha,D.Thukaram, An approach for evaluation of transmission costs of real power contracts in deregulated systems, *Elsevier Electric Power System Research,* 2004, 141-145.

[3] J. Bialek, Tracing the flow of electricity, *IEE Proceedings Generation Transmission & Distribution,* Vol.143, No.4, 1996, 313-320.

[4] F. F Wu, Y Ni, & P Wei, Power transfer allocation for open access using graph theory – fundamentals and applications in systems without loop flows, *IEEE Transactions on Power Systems*, Vol.15, No.3, 2000, 923-929.

[5] D. Kirschen, R. Allan, & G. Strbac, Contributions of individual generators to loads and flows, *IEEE Transactions on Power Systems,* Vol.12, No.1, 1997, 52-60.

[6] Hussain Shareef and M.W Mustafa, Real and Reactive Power Allocation in a Competitive Market, *WSEAS Transactions on Power Systems* Issue, Vol.1, No. 6, 2006, 1088-1094.

[7] Bustamante-Cedeno, E, Allocation of Transmission Charges for Real-Power Transactions Using Markov chains, *IET Generation, Transmission and Distribution*, Vol1, No. 4, 2007, 655-662.

[8] M.W. Mustafa, H. Shareef, M.R Ahmad, An Improved Usage Allocation Method for Deregulated Transmission System, *in Proc. IPEC 2005 International Power Engineering Conf,* 2005.

[9] A. Gomez Exposito, J.M. Riquelme Santos, T. Gonzalez Garcia, E.A. Ruiz Velasco, Fair allocation of transmission power losses, *IEEE Transactions on Power Systems,* Vol.15, No. 1, 2000, 184-188.

[10] A. Zobian, M.D.Ilic, Unbundling of transmission and ancillary services, *IEEE Transactions on Power System,* Vol.12, No. 2, 1997, 539-548.

[11] D.Tuglie, F.Torelli, Nondiscriminatory System Losses Dispatch Policy in a Bilateral Transaction-Based Market, *IEEE Transactions on Power Systems,* Vol.17, No. 4, 2002, 992-1000.

[12] D.Tuglie, G.Patrono, and F.Torelli, Real and Reactive Power Allocation In Bilateral Transaction Markets, *WSEAS Transactions on Power Systems* Issue, Vol.3, No. 4, 2004, 821-827.

[13] J.H. Teng, Power flow Loss Allocation for Deregulated Transmission Systems, *International journal of Electrical Power and Energy Systems,* Vol.27, 2005, 327-333.

[14] R.Reta, A.Vargas, Electricity tracing and loss allocation methods based on electric concepts, *IEE Proceedings Generation Transmission & Distribution,*Vol.148, No. 6, 2001.

[15] Garng M.Huang, H.Zhang, Transmission Loss Allocations and Pricing Via Bilateral Energy Transactions, *IEEE/PES Summer Meeting,* 1999, 720-725.

[16] J.Pan, Y.Teklu, K.Jun Review of usage-based transmission cost allocation methods under open access, *IEEE Transactions on Power System,* Vol.15, No. 4, 2000, 1218-1224.

[17] Rudnick, H.Palmar. R et al, Marginal pricing and supplement cost in transmission open assess, *IEEE Transactions on Power System,* Vol.10, No. 2, 1995, 1125-1142.

[18] J.W. Marangon Lima, Allocation of transmission fixed charges: an overview, *IEEE Transactions on Power System,* Vol.11, No. 3, 1996, 1409-1418.

[19] R.Haque, N.Chowdhury, An Artificial Neural Network Based Transmission Loss Allocation For Bilateral Contracts, *in Proc. Canadian Conference on Electrical and Computer Engineering,* 2005, 2203-2207.