ONLINE MONITORING OF MAXIMUM ALLOWABLE LOAD AT DIFFERENT BUSES USING ABC ALGORITHM AND ARTIFICIAL NEURAL NETWORK

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Abstract: *The power demand is increasing day by day. It is essential to determine the maximum load that can be imposed at each load bus. The maximum allowable load is the maximum load that can be applied at different load buses without violating the voltage at these buses. In this paper, the maximum loadability limit that can be imposed at different buses of power system is determined by using Artificial Bee Colony algorithm (ABC). The loadability limit is calculated with and without line outages. The results obtained using the proposed hybrid algorithm is compared with the results obtained by existing algorithms. Even though the algorithm provides better results than the existing algorithms, it cannot be applied for on line application. For online monitoring and loading, Artificial Neural Network (ANN) is used. The trained ANN is used for the online monitoring of the buses. The proposed work is validated by testing on IEEE30 bus system*.

Key words: *Maximum allowable load; Artificial Bee Colony (ABC); Artificial Neural Network (ANN), Smart Grid*

1. Introduction:

The power system becomes stressed due to the increase of demand continuously hence it is necessary to increases the generation. Whenever generators are added it is important to analyze the line capacity, line losses and other constraints in the power system. It is also essential to operate the system under safe and secured condition. The problem in the power system may be analyzed in two ways: one to determine the voltage stability limit which is the biggest problem during last few decades. The voltage stability can be analyzed in many ways. One way is to determine the voltage stability margin which is defined as the distance between the actual loading point and the maximum loadability limit. The maximum loadability limit can be determined by using Continuation Power Flow method [1]. This method lacks with many drawbacks like singularity of the matrix near the maximum loading point. The problem may be formulated as the maximization problem and the objective function is solved with constraints. The methods like interior point method and sequential quadratic programming solve the power system stability problem with the inclusion of constraints. The major constraints to be considered are the line limits. This method also suffers with the drawback of formulation of matrices and their inverses during the each iteration [2]. The problems of all these methods are because of the solution of power flow problem.

Recently evolutionary algorithms are able to solve all optimization problems efficiently. Optimal sizing of DVR is done using DE and PSO [3]. Hence the voltage stability problem is formulated as optimization problem and Hybrid Particle Swarm Optimization algorithm is applied to determine the maximum loadability limit [4]. In this paper, the power balance equation is included in the objective function by giving suitable weight.

The maximum loadability limit is determined without considering the voltage limit at the buses. The voltage stability limit is the nose point of the PV curve after which the voltage collapse occurs. At this point, bus voltage reach the minimum value hence it is necessary to determine the maximum allowable load at all the buses. This allowable limit is determined using the Evolutionary Algorithms. Hybrid PSO algorithm is applied to determine the maximum allowable load [5]. In this algorithm, load is uniformly increased in all the load buses until bus voltages are violating. In practical load will not be same in all the buses hence the load increase should be different. Hybrid DEPSO algorithm was proposed to determine this maximum point in which load is randomly increased in all the buses. By using this method, the maximum load that can be applied to each load bus is determined [6].

All the above analyses are carried out under static condition. Since there are certain cases when contingencies occur in the power system and also the maximum load that can be applied is to be determined under such contingencies. This paper proposes Artificial Bee Colony algorithm to determine the maximum allowable load under various line outages. This method can be applied only during off-line, since the time taken by the algorithm is high. In this paper, neural network is applied to determine the maximum allowable load under on-line condition also.

The paper is organized as follows section 2 describes the formulation of the problem as optimization problem. Section 3 describes the overview of ABC algorithm and Artificial Neural Network. In section 4 proposed algorithms is discussed and results and discussions are given as section 5. Finally conclusion is given in section 6.

2. Problem Formulation:

Objective:

The main objective of the problem is to maximize the load at different buses. The loadability

$$Max[\lambda_i] \qquad i = 1\ to\ NLB \qquad (1)$$

Where NLB is the Number of Load Buses

Subject to Constraints

Power flow equation

$$P_{gi} - (P_{di} + \lambda_i) - \sum V_i V_j Y_{ij} \cos(\theta_{ij} + \delta_j - \delta_i) = 0 \qquad (2)$$

$$(Q_{gi} - Q_{di}) - \sum V_i V_j Y_{ij} \sin(\theta_{ij} + \delta_j - \delta_i) = 0 \qquad (3)$$

$$V_{imin} \le V_i \le V_{imax} \qquad (4)$$

$$Q_{imin} \le Q_i \le Q_{imax} \qquad (5)$$

3. Optimization Algorithm

3.1 Overview of Artificial Bee Colony Algorithm:

Swarm intelligence is widely applied for the engineering optimization problems.

Three major mechanisms in swarm intelligence are:

- Food Sources: The assessment of a food source depends on many factors such as its closeness to the nest, its prosperity or concentration of its energy, and the ease of take out this energy.
- Employed Foragers: They are connected with a different food source which they are currently exploiting or are "employed" at. They carry with them information about this particular source, its distance and direction from the nest, the effectiveness of the source and share this information with a certain probability.
- Unemployed Foragers: They are repetitively at look out for a food source to exploit. There are two types of unemployed foragers: scouts, searching the environment surrounding the nest for new food sources and onlookers waiting in the nest and establishing a food source through the information shared by employed foragers.

Ant Colony and Particle Swarm Optimization (PSO) are some examples of swarm intelligence. Artificial Bee Colony (ABC) Algorithm is an optimization algorithm which works based on the intelligence of the honey bee swarm. It has been proven that ABC provides better optimized result than PSO [7]. Hence in this paper ABC algorithm is applied to determine the maximum allowable load of the system.

3.2 Steps involved in ABC Algorithm:

- Bee Initialization: Number of food sources is initialized randomly and fitness of each food source is computed. This task is performed by the initial scout bee and hence supports exploration. The best food source is memorized by the bee
- Employed Bees: In this function an artificially employed bee generates a random solution that is a mutant of the original solution using the formula given in equation (6)

The formula for producing a candidate solution from the existing is described below:

$$V_{ij} = x_{ij} + \emptyset_{ij}\,(x_{ij} - x_{kj}) \qquad (6)$$

where k: {1,2,….. Number of Employed Bees}

j: {1,2,….D} are randomly chosen index

D: Number of parameters to optimize

k and i : both are randomly chosen

φi,j: random number [-1,+1]

- After each candidate source position $V_{i,j}$ is produced and then evaluated by the artificial bee, its performance is compared with that of $x_{i,j}$. If the new food has equal or better nectar than the old source, it is replaced with the old one in the memory. Otherwise, the old one is retained. In other words, a greedy selection mechanism is employed as the selection operation between the old and the current food sources.

On looker Bee: An onlooker bee chooses a food source depending on the probability value associated with that food source, *pi, calculated by:*

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \qquad (7)$$

- Scout Bees: The trial parameter is defined for those solutions that are exhausted and not changing. This function determines those food sources and abandons them [7-11]

3.3 Overview of Artificial Neural Network:

Artificial Neural Networks are widely applied for classification [12] to [14]. The ANNs are widely used in fault classification in the area of power systems. Here it is applied to predict the maximum loading point and the corresponding voltages. For the on-line monitoring, we need to train the network with the input parameters of number of buses, lines, loads, generation and the line outage with the outputs of maximum loading point, bus voltages at the maximum loading point. The input and output parameters are normalized and are used for training. In this work well known Levenberg-Marquardt back propagation algorithm is applied for training the ANN. The Error and regression graphs are shown in fig.5.5 and 5.7.

4. Proposed Algorithm:

4.1 Steps for proposed ABC algorithm

(i) Initialize the food sources for X_{ij} *(λ_i) where i is the bus number and j is the bee size

(ii) Evaluate the function value for each X_{ij} using equation For each X_{ij} run the NR load flow, if it converges, $\sum_{i=i}^{NLB} X_{ij}$ is taken as function value, if doesn't converge, function value is considered as 0 (very minimum such bees are not involved in the competition)

(iii) Determine the new food sources V_{ij} for employed bee using the equation (6) and evaluate the function value as described in step(ii)

(iv) Select X_{ij} or V_{ij} comparing the function values

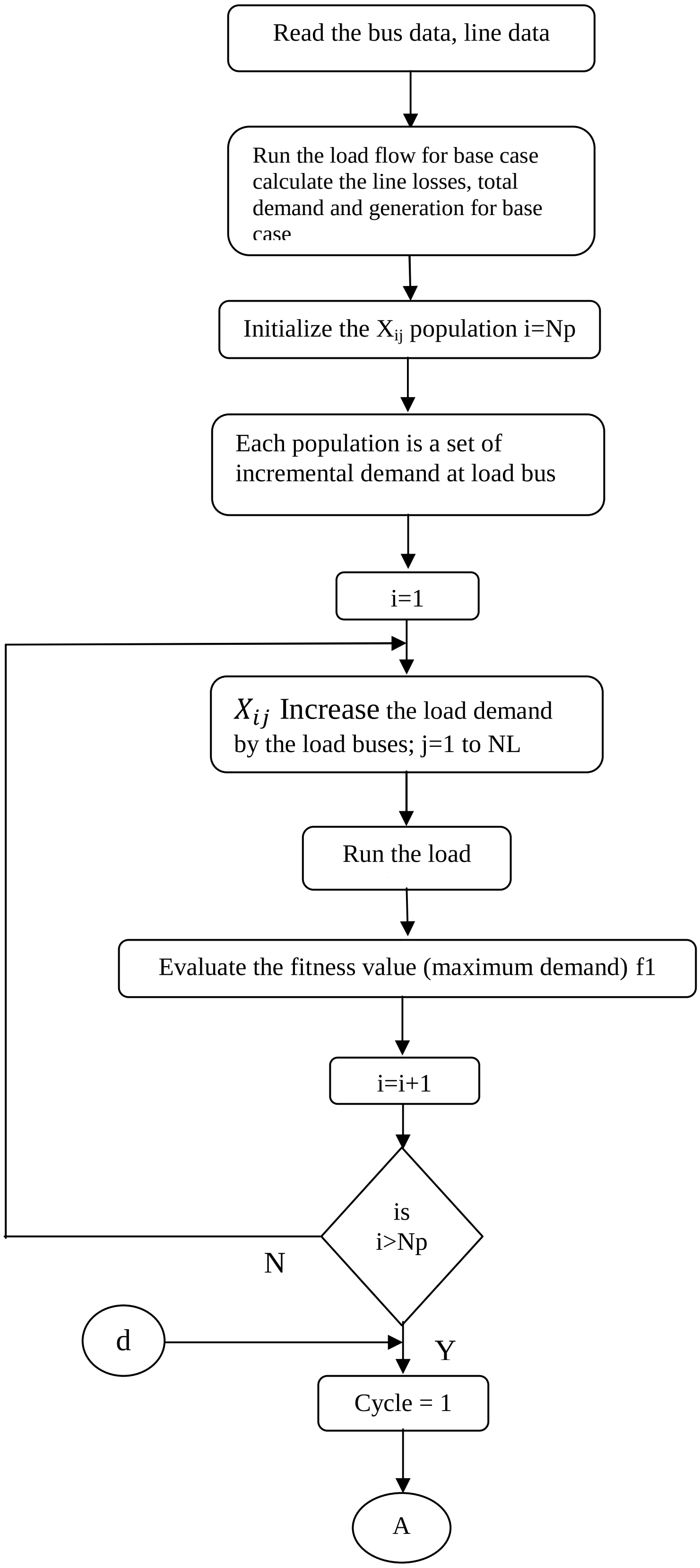
(v) Determine the probability and determine the food source of on looker bee

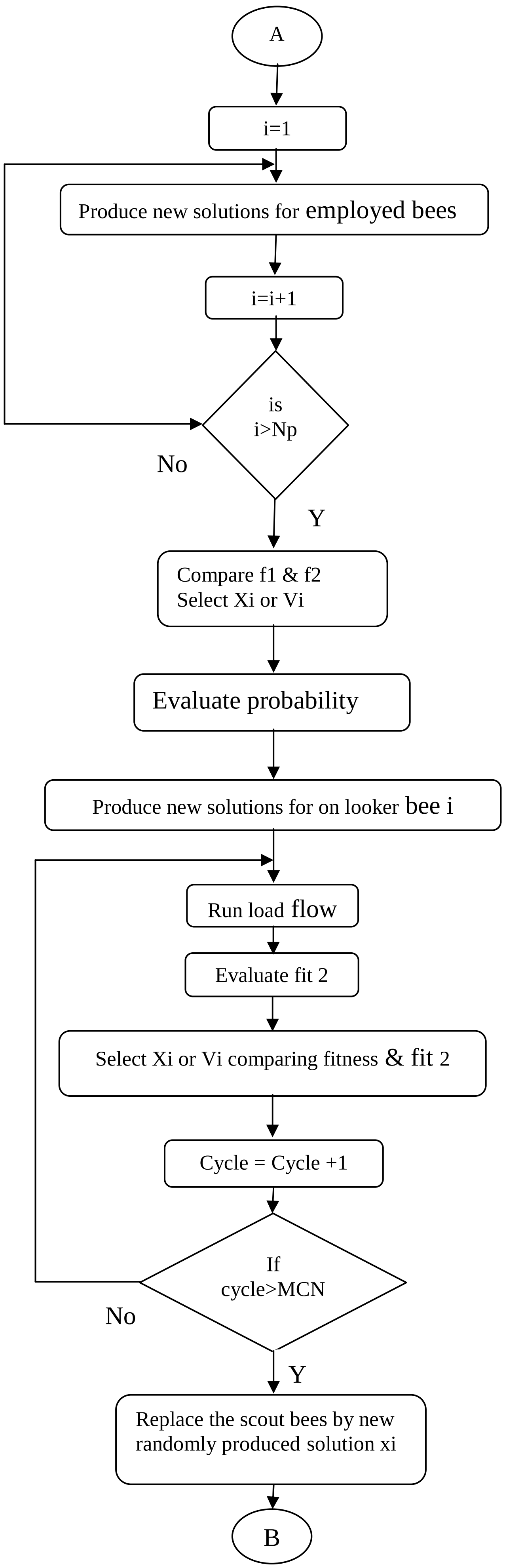
(vi) If there is no improvement replace the scout bees using the new randomly chosen value (λ_i)

(vii) Memorize the best value

(viii) Repeat the steps for fixed number of iterations

4.2 Flow chart for the proposed work





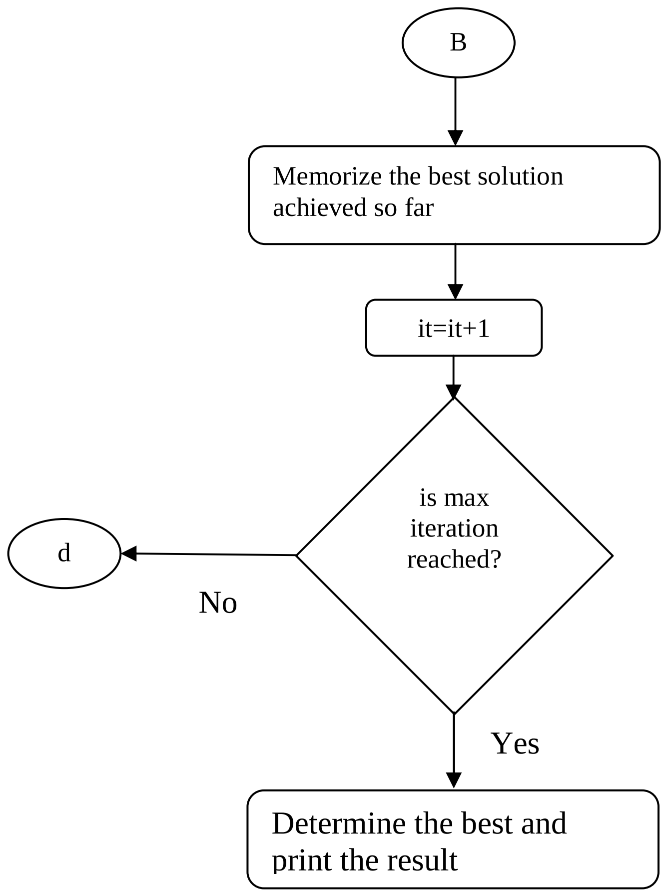


Fig.4.1 flowchart for ABC algorithm

5. Result and Discussion

5.1 Data collection

1. The maximum allowable load at each load bus is calculated using the ABC algorithm as the flowchart shown in fig.1
2. The above steps are repeated with each line outage and the combination of the outages
3. The results obtained from ABC algorithm is given as the training data for ANN
4. The sample data set is given in table.
5. The ANN is trained using Levenberg-Marquardt algorithm
6. The trained ANN is used for the online monitoring of maximum load that can be applied at each bus during different contingencies.

Training Data:
Using the ABC algorithm
Base case Demand: 283.4 MW
For ANN training 10 hidden neurons are used. Training and validation are done using MATLAB

Table5.1: Maximum Allowable load obtained using ABC Algorithm (IEEE30 bus system)

S.No.	Line Outage Number	Incremental load (MW)	Maximum Allowable Load (MW)
1	without line outage	90.80	373.84
2	1-2	85.67	369.09
3	1-3	69.79	353.19
4	2-4	76.93	360.33
5	3-4	73.69	357.09
6	2-5	83.38	366.78
7	2-6	74.33	357.73
8	4-6	72.24	355.64
9	5-6	74.09	357.49
10	6-7	74.81	358.21
11	6-8	73.25	356.65
12	6-9	65.4	348.8
13	6-10	77.48	360.88
14	9-11	70.13	353.53
15	9-10	81.65	365.05
16	4-12	75.33	358.73
17	12-13	80.48	363.88
18	12-14	76.56	359.96
19	12-15	72.36	355.76
20	12-16	77.82	361.22
21	14-15	73.43	356.83
22	16-17	84.89	368.29
23	15-18	51.42	334.82
24	18-19	67.39	350.79
25	9-20	61.68	345.08
26	10-20	68.36	351.76
27	10-17	74.54	357.94
28	10-21	74.35	357.75
29	10-22	68.57	351.97
30	21-22	70.76	354.16
31	15-23	68.23	351.63
32	22-24	70.68	354.08
33	23-24	63.32	346.72
34	24-25	71.32	354.72
35	25-26	65.54	348.94
36	25-27	72.12	355.52
37	28-27	65.24	348.64
38	27-29	73.66	357.06
39	27-30	77.31	360.71
40	29-30	85.25	368.65
41	8-28	72.12	355.52
42	6-28	74.54	357.94

Table 5.3 Comparison of convergence time

DEPSO[5]	Proposed Hybrid ABC
548.82 seconds	340.23 seconds

Fig.5.1 shows the sample convergence graph of ABC algorithm without line outages. Fig5.2 to Fig.5.4 depict the convergence graphs with line outages 1-2, 1-3, 2-4. Similarly the graphs are obtained for remaining line outages and the combination of the line outages. Convergence graphs show the effectiveness of the ABC algorithm. The algorithm is run for 1000 iterations. Even though, number of iterations is high, it gives consistent results. The algorithm is tested for consistency by 20 trials. During all the trials the final results are same. This shows that the statistical measure of zero standard deviation. Fig 5.5 to 5.8 depicted the training and testing performance of ANN.

Without transmission line outage (loadability – 0.9080 pu)

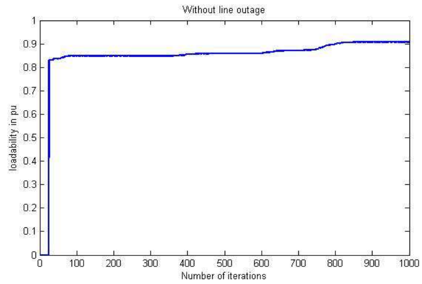


Fig.5.1 without transmission line outage

Transmission line 1-2 outage (loadability– 0.8567pu)

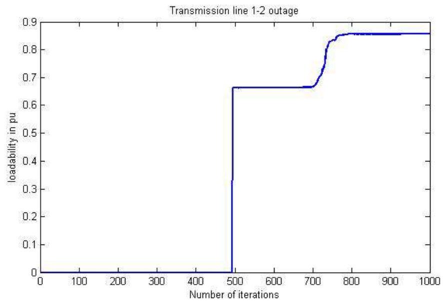


Fig.5.2 transmission line 1 – 2 outage

Transmission line 1-3 outage (loadability – 0.6979pu)

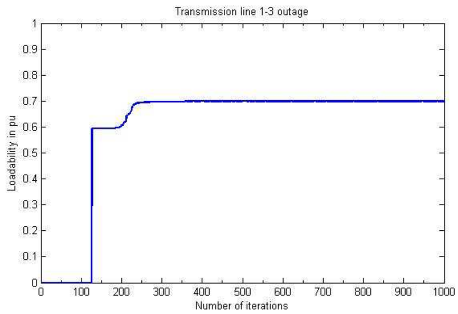


Fig.5.3 transmission line 1 – 3 outage

Transmission line 2-4 outage (Loadability - 0.7693pu)

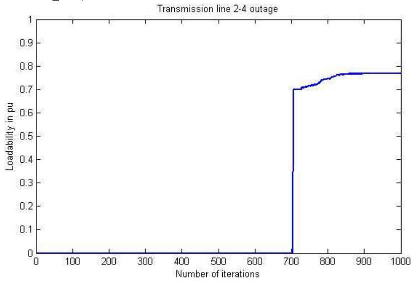


Fig.5.4 transmission line 2 – 4 outage

Table 5.2 Individual Load Bus maximum loading

Line outage → / Bus No. ↓	Without line outage	1-2	1-3	2-4
3	0.06	0.003	0.029	0.031
4	0.13	0.149	0.040	0.040
6	0.03	0.097	0.069	0.061
7	0.05	0.011	0.032	0.058
9	0.02	0.045	0.064	0.063
10	0.03	0.060	0.003	0.014
12	0.08	0.013	0.006	0.047
14	0.09	0.034	0.010	0.045
15	0.03	0.091	0.014	0.047
16	0.02	0.035	0.043	0.055
17	0.04	0.000	0.052	0.005
18	0.00	0.017	0.028	0.025
19	0.03	0.018	0.047	0.036
20	0.14	0.008	0.031	0.018
21	0.00	0.145	0.039	0.062
22	0.02	0.010	0.000	0.048
23	0.02	0.012	0.051	0.071
24	0.07	0.041	0.078	0.000
25	0.00	0.000	0.013	0.006
26	0.00	0.000	0.000	0.010
27	0.02	0.030	0.020	0.000
28	0.02	0.038	0.027	0.025
29	0.01	0.001	0.003	0.000
30	0.00	0.002	0.000	0.004

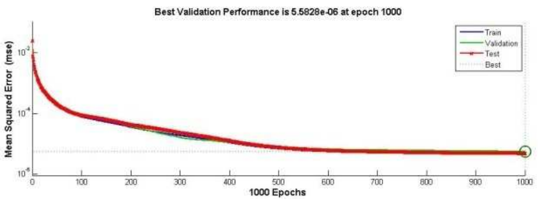


Fig.5.5 Error graph of ANN

Histogram

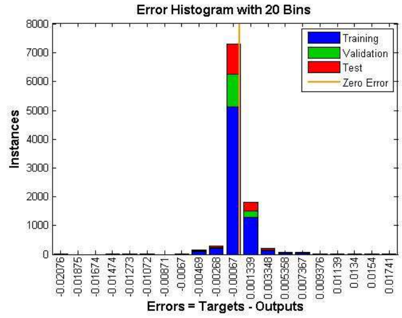


Fig.5.6 Histogram

5.2Training

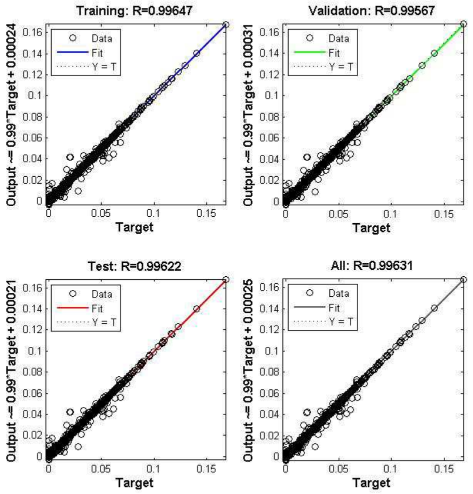


Fig.5.7 regression graphs

The very low value of MSE and the unity regression graphs show the effectiveness of the ANN training.

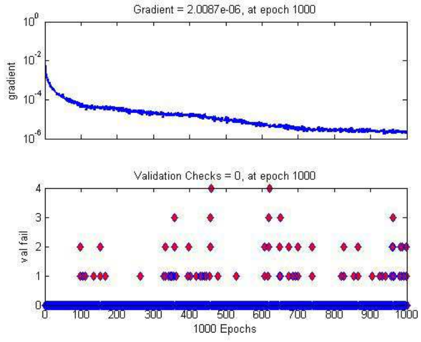


Fig.5.8 ANN training

6. Conclusion:

The Artificial Bee Colony algorithm is applied to determine the maximum allowable load. The voltages at the buses are kept within the limits. The maximum allowable loads and the corresponding bus voltages are determined. The results are given as the training inputs to the artificial Neural Network. The trained ANN is applicable for the on-line monitoring of the power system under contingency. During each line outage, the trained neural network predicts the load that can be applied at each bus and the corresponding voltages. The load can be increased from base case 0f 283.4MW with the minimum value of 334.82MW and the maximum value of 373.83MW with different line outages, to operate the system safely under contingency.

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