Optimal Restoration of Distribution System by Using PSO and ANN

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***Abstract*—Service restoration is an important aspect of power system design that caters the restoration of power to an un-faulted area under blackout after an emergency condition. The power system operators have the principal objective of minimizing the inconvenience occurred to consumers by isolating only the faulty area while providing the power to unaffected areas as much as possible. Their objective of providing service to customers is subjected to further constraints such as distribution system configurations, power available in the network, and the current carrying capacity of the distribution lines or feeders. Once a fault takes place, the number of customers in the blackout area mainly depends upon the effectiveness of the load restoration mechanism. Currently, the power system operators respond by implementing a pre-defined restoration schedule based on the previous human knowledge. While this may serve the purpose of power restoration to some extent. There is typically a large number of feeders with even larger number of switches in a distribution system and it is not humanly possible to restore the service to an out of service area solely based on past experiences. Many algorithms have been proposed to serve the purpose of restoration with each one having certain merits and demerits. This paper presents an effective and globally optimal restoration mechanism using Particle Swarm Optimization (PSO) and Artificial Neural Network (ANN).**

***Index Terms*—ANN; Distribution System; PSO; Restoration.**

I. INTRODUCTION

The electric power has turned into a most extreme need for life. A nonstop supply of electricity is very important in every field of life. It is equally important in the commercial and non-commercial areas like; industrial, educational, banking and in the medical field as well. All these mentioned areas are the major consumers of electricity. These fields cannot survive a single day without the constant supply of electricity [1]. If electricity is not provided to them for a while they will completely become not functional. This shows the importance of the reliable supply of electricity.

Enormous expenses are linked with the faulty situation. To bring the system to its normal state, the power distribution system should have to follow the predefined steps [2]. However, by using a pre-defined procedure, the success rate is very low to overcome the faults situations because the nature of these faulty situations varies in nature. Moreover, designed plans are based on the past fault histories, whereas it must work in real time. Therefore, the present fault situation may be different from the past [3]. As the result of these problems, different researchers presented different ideas. Their main aim is to propose a solution to restore the system to normal condition by restoring as much load as possible after an emergency state occurs.

The major aim of this paper is to show the effectiveness of using PSO and ANN algorithm for optimally restoring the distribution system after the contingency has occurred. This paper presents the modified IEEE 33 radial distribution network for such simulation. Simulation is made in three steps. Firstly, a load flow analysis is run to get steady state status of the modified IEEE 33 radial distribution network. Newton-Rapson Method (NRM) was used for this analysis. Secondly, a contingency/fault was added to generate an emergency condition. Finally, a combined technique of PSO [4] and ANN [5] was applied to restore the system. It was performed by using tie and sectional switches to reconfigure the system. This technique has enabled to restore the maximum possible load. Line current carrying capacities and the priority of load has been taken into consideration for optimal restoration.

II. LITERATURE REVIEW

A. Artificial Neural Network

An ANN network is the mathematical representation of biological neural network (NN) which can copy the working nature of it [6]. A neuron which is the basic unit of biological and as well as of ANN consists of input, output and a nonlinear function. For each input, corresponding weight is assigned in the range of -1 and 1. Input is multiplied by the weight. All inputs are added. The resulted sum is given to nonlinear function and its output is calculated. The overall NN consists of input, output and hidden layers of neurons. Inputs are the program inputs and output are the output of the last neuron. All the hidden layer neurons are connected in the feed forward manner i.e. first layer neuron is connected to all program inputs then first layer neuron is connected to next layer and so on. The output is taken from the last connected neuron [7]. The advantages of ANN are:

- Provides better results compared to other computer programs.
- It has the parallel nature so if the target is missed by any of its component it will still work.
- ANN is the machine learning algorithm, so it will learn the trends from the training network. Afterwards, it does not require any data and therefore it can accurately classify the testing data by the learning trends.

The drawbacks of ANN are:

- The design of microchips should be copied because of unique relation to the engineering of ANN.

- For some desired output, it requires a lot of processing time to set its parameters.

B. Particle Swam Optimization

To reduce the reactive and active power losses and to improve the voltage profile, PSO finds the optimal location for the reconfiguration switches. It has many applications in the radial distribution system for optimization and is very effective. The advantages of PSO are:

- It has less sensitivity to changes in the scaling of designing variables [8].
- For concurrent processing, it can be easily parallelized derivative-free
- It globally searches the optimal solution for the problem and is very efficient [9].

The disadvantages of PSO are:

- The tendency to a fast and premature convergence in mid optimum points.
- Slow convergence in refined search stage (weak local search ability) [10].

C. Load Flow Analysis Methods

Following two methods can be used for load flow analysis of the system:

1. Gauss-Seidel method (GSM)
2. Newton-Raphson method

These both methods give nearly the same answers. The difference in both methods is of convergence rate. NRM convergence rate is higher than the GSM because it requires derivatives thus by reducing the number of iterations.

Normally the distribution systems are very strong enough to face troubles. However, some natural and human errors can make them more prone to faults which lead them to the emergency situations. If the system is not recovered from the emergency state or if not isolated the faulty part, the whole system will shut down causing big economic loss and loose of trust of the customers.

In this paper, a modified IEEE 33 bus (radial distribution system) is used as shown in Figure 1.

In an emergency condition to protect the system from the complete shutdown, some of the big loads need to be turned off. An automatic system is not so much intelligent in the situation of shedding and restoring the loads in such situation. It has been the great concern for many researchers. Different researchers tried to equip an algorithm which can do the load restoration for the system [3]. A number of approaches have been provided which includes controlling the system by rules and mathematical modeling. Although these proposed techniques show very good results, but the implementation of these approaches on real-time scenarios is not possible. These algorithms can be categorized in the longtime requirement for restoration plan to be implemented.

III. METHODOLOGY

This paper focuses on the load restoration and load allocation in power distribution system by using PSO and ANN. Its core objective is to minimize the loss of load by optimally reconfiguring the system with certain constraints. From the literature review, it has been found that the limitation of the existing techniques which includes small test circuits, a minimum amount of time required for the restoration is at the expense of the quantity of load recovered. This core idea has been taken to develop an algorithm in PSO to find the most optimal system configuration. Hence by considering some restrains the system's optimal state is possible to be found. Fitness function and calculation of the cost of each fitness function is required to implement the PSO algorithm. In this paper, PSO as an optimization algorithm and ANN with multilayered perception (MLP) are used for load restoration

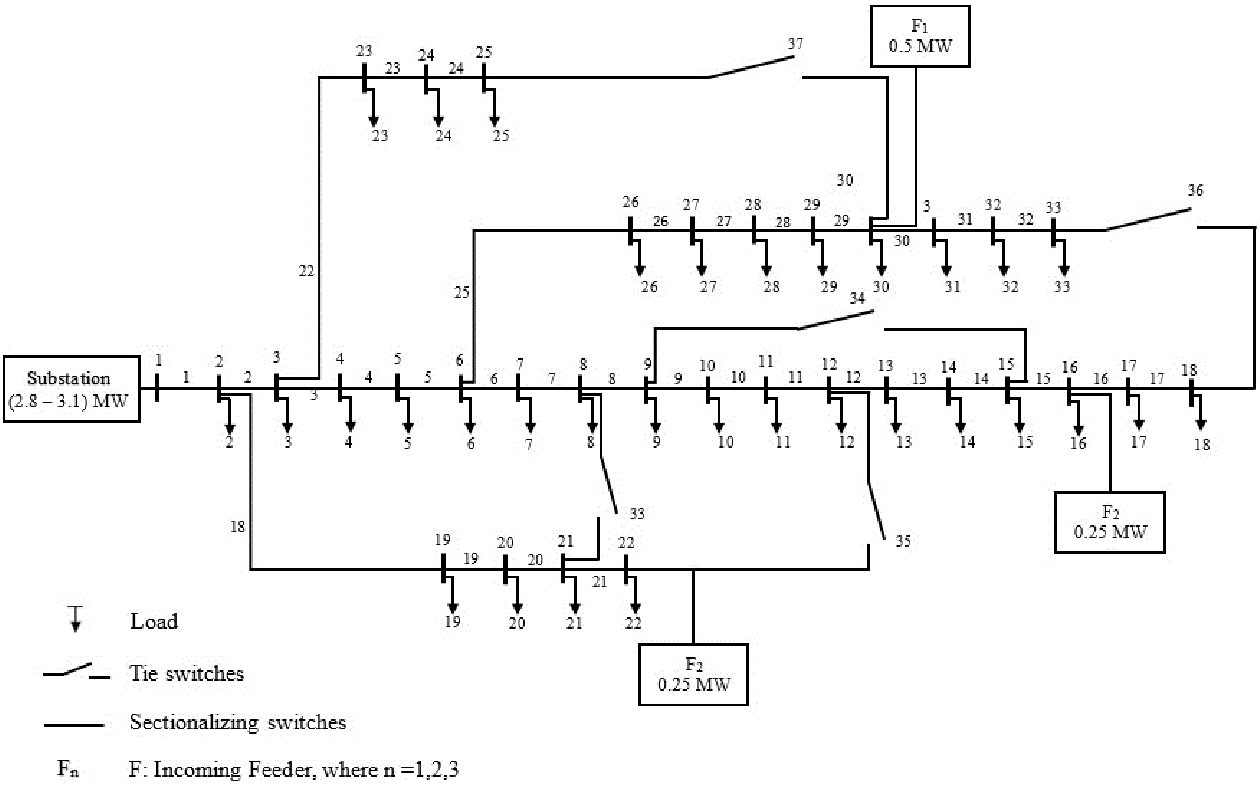

Figure 1: Modified IEEE 33 bus System

and allocation.

A. Particle Swarm Optimization

There are different ways of optimization of radial distribution system one of the methods is to optimize the system by using switches. In the case of modified IEEE 33 bus system, there are 33 sectional switches which are normally closed and 5 tie switches which are normally open. To get the best configuration, voltage profile analysis is used. The one with minimum voltage profile is better than the other and will be considered as more optimal configuration. This process can be done by using optimization algorithms like GA, PSO, and ANN etc.

To obtain the optimal solution of the network by reconfiguration of switches such that power loss can be minimized, we performed following steps for PSO implementation:

1) Initial declaration of the variable, and defined values of iteration and constants.
2) The initial definition of switches combination from which switches will be selected.
3) The random population is generated initially by particles.
4) Fitness value of each particle is calculated.
5) The velocity and position of each particle are updated.
6) The fitness and particle values (switches) for each iteration are calculated till the iteration of PSO completes.
7) One best cost particle is selected. It can be obtained by sorting all the values of cost and selecting one with lowest power loss.
8) Total cases to be evaluated are six. After the first case is completed, the next five loops are repeated from step 3.
9) After total six cases are completed the program is terminated.

B. Particle Swarm Optimization

In this paper reconfiguration of the system is done by using regression technique of ANN. It comprises of two parts. Load balancing index (LBI) and system loss are evaluated in the first part of the scheme; while the optimal configuration is done in the second part.

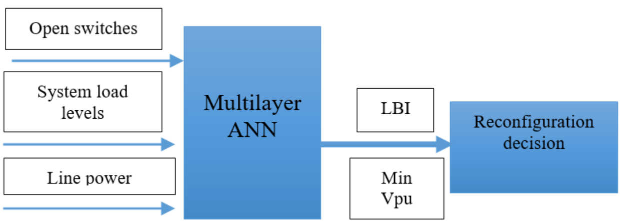

Figure 2: Configuration of ANN

LBI and system loss are analyzed by using multilayer ANN technique. Location of open switches, levels of load, and line power rating are the inputs of the system as shown in Figure 2. ANN gives LBI and minimum voltage profile value. ANN assigns weights to its inputs which are multiplied by it and produce the corresponding output. If the output is not in the desired range the NN changes the values of assigned weights and are known as back-propagation algorithms. The output of the network will take from the last connected neuron of the last layer. Consider the outputs of the previous layer neurons to be x_i, the output of the present layer neuron, j can be calculated by using the Equation (1):

$$net_j = \sum_i w_{ij} x_i \tag{1}$$

where: w_{ij} = Weights for the input i for neuron j

In the same way, the LBI can be found by using Equation (2):

$$LBI = \sum_i^{NB} W_i \left(\frac{P_{bi}}{P_{bi}^{Max}} \right)^2 \tag{2}$$

where: P_{bi} = Current flow through a wire
W = Weighting factor

ANN implemented in this work is by using the following methodology. Firstly priority was assigned to switches. In the first case among the switches 17, 18 and 19; switch 17 was assigned the highest priority. Similarly, for the next case among switches 37, 38 and 39; switch number 37 was assigned the highest priority. The switches with the lowest priority will shed first while the switches with the highest priority will be stored. The step of the simulation is as follows:

1) After generating 6 different cases by PSO, training and testing data for ANN is generated.
2) The input to ANN are:
   - Normally open switches
   - System load level
   - Line power ratings

   While the outputs are:
   - Voltage in Pu
   - Index value
3) Load levels are varied for each caseload flow analysis. The result for each level in each case is considered as part of a database. The database is divided into two sections testing database and training database which is used to train the ANN and test the ANN.
   - The variation of load in database creation for training data is from 30% to 200% with the difference of 10% and hence created cases are 108 from 6 configurations (18 cases for each configuration).
   - The variation of load in database creation for testing data is from 95% to 155% with the difference of the 20% and hence created cases are 24 (6 cases for each configuration).
4) After training data of NN a fitted network is obtained which will predict the minimum voltage profile and indexes while considering the dissimilar load levels and different configuration initials.
5) Testing of ANN is done by using the testing data. The best-obtained network is stored, which is used in future for reconfiguration.

The test condition of the test cases are as follows:

1) Open switch cases for training of ANN

Case 1 is considered as the randomly chosen five switches are open as shown in Figure 1. In the same way, choosing the different combination of five switches, total six cases were made as shown in Table 1.

Table 1
Open Switch Cases For Training of ANN

Case No.	Open Switches
1	33, 34, 35, 36, 37
2	9, 32, 27, 13, 13
3	3, 10, 14, 30, 33
4	5, 13, 21, 31, 25
5	18, 11, 21, 36, 37
6	19, 13, 35, 31, 22

2) *Load variation cases for training of ANN*

For every case, the load is changed from 30% to 200% creating 108 cases. These cases were used for training of ANN. To make a single case of training, data input parameters were set accordingly and then NRM load flow analysis was applied to get the output data. Similarly, the network was trained for all the above cases. After that, the network was tested on some test cases.

3) *Load variation for testing of ANN*

For testing cases, the loads vary from 95 to 155 with the difference of 20 for the total 6 cases (C1, C2, C3, C4, C5, C6) as shown in Table 2.

Table 2
Open Switch Cases For Training of ANN

Increase Load, %	Cases					
95	C1	C2	C3	C4	C5	C6
115	C1	C2	C3	C4	C5	C6
135	C1	C2	C3	C4	C5	C6
155	C1	C2	C3	C4	C5	C6

IV. RESULTS AND SIMULATION

A. PSO Results

To find the optimal system reconfiguration PSO was implemented. As discussed in the previous methodology section that initial parameters were passed to the PSO algorithm. During this period the total number of iterations was set to 60. Whereas the dimension of search space was fixed at 5. The reason to fix the values of search space as 5 is due to 5 switches configurations which are needed for a single case. PSO is a stochastic method based technique. Therefore, there is a possibility that it may get different solutions at different times. This also does not guarantee that it will get different results in every case. To confirm this, the simulation was run to get the switches configuration and following were the different switch configurations generated by the PSO code.

B. ANN Testing Results

After training of the ANN, it is important to check the accuracy of the system. Different people use different techniques to check the accuracy of the system. In this paper, the following two techniques are used to check the accuracy of the system.

- Mean absolute error calculation (MAEC)
- Pictorial representation of results

By applying the MAEC techniques, the obtained accuracy is approximately 99%. The pictorial representation of the graph is shown in Figure 3. Few test cases were selected for this purpose. The graph was plotted between the actual output of test case and the predicted values. It can be seen in the Fig. 3 that the results were very good in similarity.

C. Normal Case

The analysis of modified IEEE bus 33 by NRM, depicts the plotted voltage profile for analyzing the stability of the system. Normal case voltage profile is as shown in Figure 4. In this case, all the sectional switches are closed. Whereas, all the tie line switches (33, 34, 35, 36 and 37) are open.

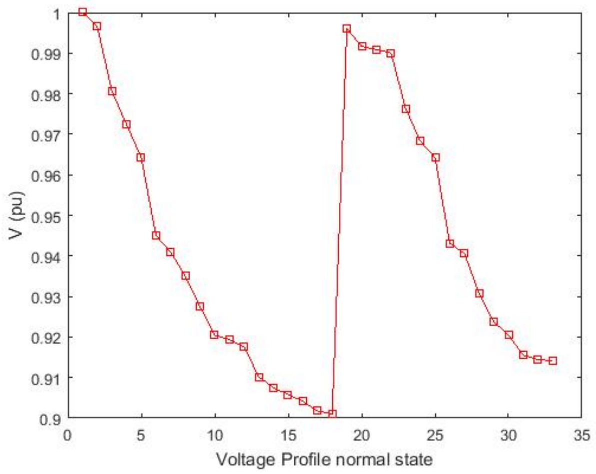

Figure 4: Voltage Profile For Normal Condition

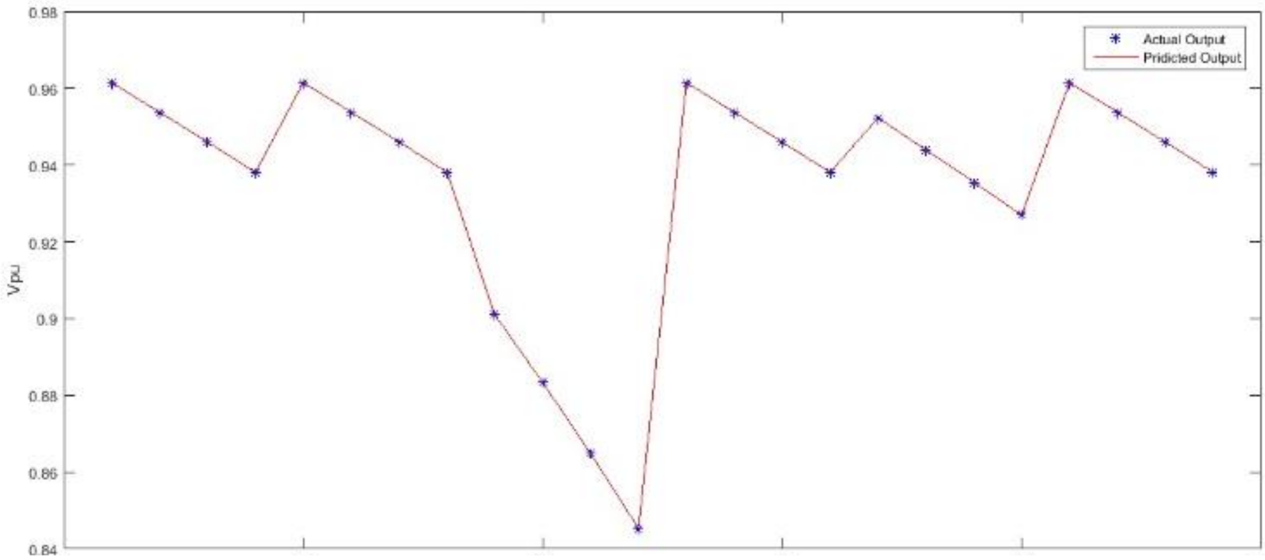

Figure 3: ANN Output Testing

D. After Contingency State

An emergency stage was created virtually. For this, the fault was added to both the loads and feeders. It is worth noting that the system has the capability to handle all types of problems. The contingencies were checked individually as well as collectively. To generate the contingency load was added at 15, 16 and 17. While for a restoration of the system in the emergency state, the sectional switch number 11 was opened. Figure 5 shows the result of after such contingency state.

From Figure 5 there is no voltage for bus 12 until bus 18. It is because of the sectional switch number 11 is opened. And hence there is no power flowing through that part.

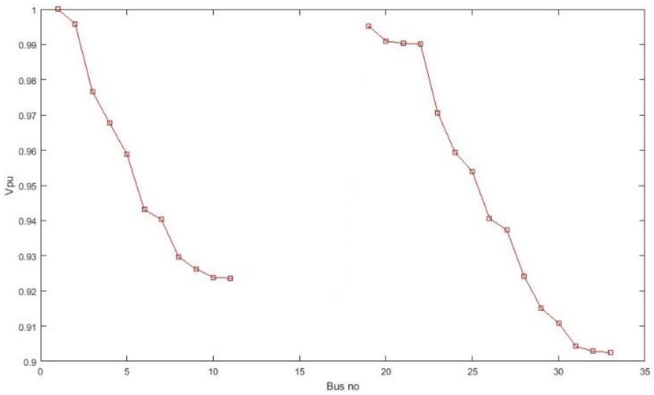

Figure 5: Voltage Profile After Contingency

E. After Restoration

PSO and ANN based techniques were used to reconfigure the system. After the reconfiguration, both the load and voltage profile of the system were analyzed. System load was restored considering the priority. For this load priority was added at the beginning of the program. Priority was given to system for the sensitive loads like that of hospital and university. Which means that if the power becomes available to the system, then firstly all these loads and then the other loads will be restored.

As the contingency was also added to the feeder so the power was not enough to restore all the loads. The voltage profile as shown in Figure 6 is for system restoration using load priority. It can also be seen that the voltage profile of system has also been improved significantly.

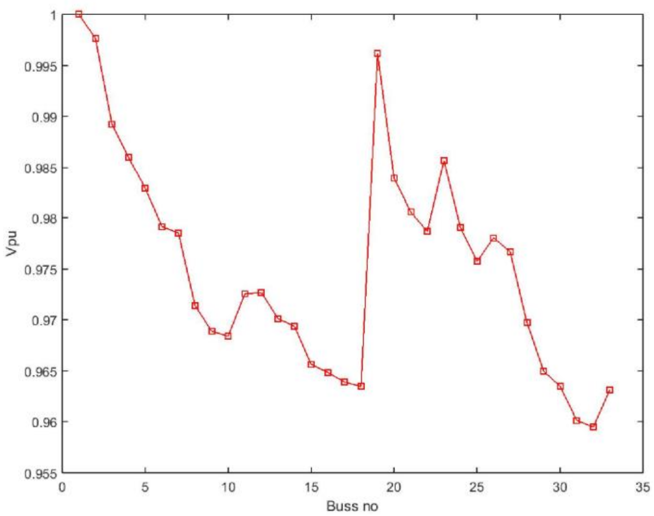

Figure 6: Voltage Profile After Reconfiguration

F. Load Restoration

To analyze the load restoration a contingency state was added at the feeder. Four stages of load status in normal, after contingency, after contingency without priority loads and after contingency with priority loads is depicted in Table 3.

Table 3
Open Switch Cases For Training of ANN

States	Active load	Reactive load
Normal state	3.715	2.30
After contingency state	3.210	2.30
After reconfiguration without priority	-	-
After reconfiguration with priority	3.475	2.21

From Table 3, it is clear that after contingency added to the system, it was not able to restore without counting the priority loads.

V. Conclusion

Following conclusions were drawn from the results after reconfiguration of a system by using PSO and ANN scheme. By using this scheme system loss is decreased significantly. Therefore, the system can have the capability to handle more load. Other inferences are:

1. PSO gives the most optimal configuration of switches.
2. ANN proved to be an effective tool for solving the system reconfigurations problems. LBIs were predicted accurately and quickly. Correct prediction of the LBI is important because our system reconfiguration depends upon it.
3. If the PSO part was kept constant, then every time ANN gave the most optimal solution.
4. After the system went into contingency most of the loads were restored and voltage profile of the system also improved.
5. For the different load levels, the final configurations are different because of line capability limits.

Following are the limitations of using this technique:

1. There were total 108 cases at different loads for the training of ANN network. If inputs come from these cases it will give perfect results. However, in the case, if the output is not from these 6 set cases it will still give the output from those cases. Therefore, it is unable to identify that whether it is a part of our input or not.
2. The representation of the weights is difficult to develop. Therefore, to remove this flaw we should select the genetic operators carefully.

VI. Future Work

In this paper, PSO and ANN techniques were used for the optimization of modified IEEE 33 bus radial distribution system. However, in future same technique can be used for the optimization of a meshed distribution system. This scheme can be used for optimization in different problems faced by the standard bus systems such as under voltage load shedding and under frequency load shedding.

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