Intelligent Approach for Efficient Operation of Electrical Distribution Automation Systems

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Abstract— The distribution systems play a vital role in making efficient service in terms of power quality, reliability, and economy. The distribution network reconfiguration can be used for planning as well as real time control. This paper presents an efficient approach for network reconfiguration approach based on artificial neural networks. A package "DISTFLOW" is developed adopting the proposed technique. The off-line simulation results and daily load curve data are used for training of the neural network. Further the distribution system operation is optimized by selecting optimum compensation level computed by Genetic Algorithms (G.A). The proposed integrated approach is applied to 140 bus practical system of Surathkal city subdivision, of the power utility Mangalore electricity supply company (MESCOM).

1. INTRODUCTION

The electric power system consists of large number of interconnected components that work together to generate and deliver electrical power to many load points scattered over a wide geographical area. In order to satisfy the modern age power needs, it is very much essential to plan ahead for higher power generation and design of efficient transmission and distribution systems.

India is a fast developing country, which has geared itself for globalisation process. The structure of Indian power distribution is a large network comprising of various generation, transmission and distribution companies. The generation of power is with the purview of direct Government of India agencies and also provincial state agencies. The transmission and distribution of electric power is the responsibility of companies under different provincial states. Since from independence year 1947, the power sector is with the control of Government agencies. The economic reforms, which have been initiated during last decade, have yielded good results in many sectors. The power sector has been identified as a potential area and many improvement steps have been taken in all parts of the country. The measures include installation of large power generation plants, privatisation of transmission and distribution sector and implementation of energy efficient management.

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The National Institute of Technology Karnataka (NITK) was started during 1960, by Government of India to cater the needs of providing good technical education and necessary technical support for organisations in the region. In view of the concern over efficient distribution systems, NITK has been associated with Mangalore Electricity Supply Company (MESCOM) to critically analyse the existing distribution system and suggest improvements in planning and operation for the betterment of service.

The first phase was to develop a model for the dynamic planning of the distribution system. To cater this need a heuristic expert system has been developed incorporating constraints and feasibility evaluation. The next phase is to look into voltage profile improvement. This is attributed to arrival of optimum network configuration. The early studies on the network configuration were directed to the planning stage [1],[2]. In planning, the main objective is to minimize the cost of construction. Recent advances in distribution automation technology have substantially improved control and management capabilities. The general problem of loss minimization has greater effect on distribution operation decisions, which will help in planning the lay out of circuits as well as prediction of the desired configuration of the system for different contingency cases.

The problem of finding the network configuration with minimum line losses, is a mixed integer, non-linear optimisation problem has been investigated by branch and bound method. However there is no assurance of convergence and burden on computing resources is extremely high and often impractical. Heuristic rather than analytical methods appear to be more effective for feeder configuration studies. Simulated annealing method can be employed but it is computationally demanding. Recently methodologies based on Genetic Algorithm (GA) are being developed to get appropriate global optimum with less computational burden .

The distribution systems are normally configured radially for effective coordination of their protection scheme. Most distribution networks use sectionalising switches that are normally closed and tie switches that are normally opened.

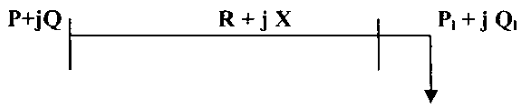
These switches are used for restructuring both at planning and operation level. The time to time modification with transfer of loads from one feeder to another feeder depending on contingency will significantly improve operating conditions of overall system. If the distribution loads are rescheduled more effectively by network restructuring, the voltage stability in the system can be improved [3]. The genetic algorithm has been applied for computation of optimum capacity of compensation in the distribution systems [4].

This paper presents an efficient network restructuring approach for time varying loads based on artificial neural networks. A generalised ANN model is presented for enhancement of stability under varying load conditions. The training data are generated from daily load curves. The test results are found matching with off-line simulation technique. The developed technique formulates the problem in such a way that all possible branches which are to be considered for branch exchanges are taken into account. The methodology can be adopted during planning stages for better commissioning of network. During any contingency the configuration can be altered for service continuity to obtain optimum network structure with minimized losses. The optimum level of compensation as determined by genetic algorithm approach further improves the operation of the distribution systems. The developed technique is applied for existing distribution system of Surathkal subdivision of Mangalore electricity supply company (MESCOM) which is the power distribution company of the region. The service area selected comprises of variety of loads and load variation on every hour is considered. The procedure of distribution planning becomes more systematic and flexible by adopting the developed technique. The principles can be extended for time to time modification of operating strategies which comes in to force to ensure efficient functioning of distribution system. In order to meet the challenges to achieve efficient performance of the distribution system , the recent trend is to automate the operation and control of distribution system owing to development of modern technologies.

2. VOLTAGE STABILITY INDEX

The voltage stability has been defined as the ability of a system to maintain voltage at all parts of the system so that with the increase of load, both the power and voltage are controllable. The methods to improve voltage stability are (i) adjust sub-transmission voltage levels at supply points (ii) automatic tap changing transformer at sub-stations (iii)additional feeders and distributors (iv) reactive compensation (v) rearranging the system and transfer of loads. This paper presents a technique with emphasis on reconfiguration and load transfer to improve voltage stability.

2.1 *Mathematical Formulation*



The real and reactive power equations have been derived [3], [4] as follows :

$$P = [R (P^2 + Q^2) / V^2] + P_l \quad (1)$$
$$Q = [X(P^2 + Q^2) / V^2] + Q_l \quad (2)$$

From the above equations it can be simplified as

$$X (P - P_l) = R (Q - Q_l) \quad (3)$$

The quadratic equation in P can be obtained as

$$AP^2 - BP + C = 0 \quad (4)$$
$$AQ^2 - DQ + E = 0 \quad (5)$$

where

$$A = (R^2 + X^2) \quad (6)$$
$$B = 2X^2P_l - 2RXQ_l + R \quad (7)$$
$$C = X^2P^2_l + R^2Q^2_l - 2RXP_lQ_l + RP_l \quad (8)$$
$$D = 2R^2Q_l - 2RXP_l + X \quad (9)$$
$$E = X^2P^2_l + R^2Q^2_l - 2RXP_lQ_l + XQ_l \quad (10)$$

The P and Q have real roots and determinants of these equations must be greater than or equal to zero.

$$B^2 - 4\,AC \geq 0 \quad (11)$$
$$D^2 - 4\,AE \geq 0 \quad (12)$$

Simplifying the equations (11) and (12)

$$4[(XP_l - RQ_l)^2 + XQ_l + RP_l] \leq 1 \quad (13)$$

The equation (13) speaks about the voltage stability index (VSI). Thus the optimum operating point is obtained for VSI $\leq$ 1.

For the radial distribution network, the total real and reactive power can be computed as

$$P = \Sigma P_{loss} + \Sigma P_{li} \quad (14)$$
$$Q = \Sigma Q_{loss} + \Sigma Q_{li} \quad (15)$$

which incorporates total real and reactive power losses and total real and reactive loads. The distribution network with main feeders, laterals and sub-laterals can be reduced to single line equivalent structure. The equivalent resistance and reactance of single line network are

$$R_{eq} = \Sigma P_{loss} / \{ (P_{leq} + \Sigma P_{loss})^2 + (Q_{leq} + \Sigma Q_{loss})^2) \} \quad (16)$$
$$X_{eq} = \Sigma Q_{loss} / \{ (P_{leq} + \Sigma P_{loss})^2 + (Q_{leq} + \Sigma Q_{loss})^2) \} \quad (17)$$

where P_{leq} and Q_{leq} are the total real and reactive loads.

For the equivalent single line network, the voltage stability index can be redefined as

$$VSI = 4[(X_{eq} P_{leq} - R_{eq} Q_{leq})^2 + X_{eq} Q_{leq} + R_{eq} P_{leq}] \quad (18)$$

For better voltage stability this index VSI need to be less than or equal to 1.

3. Best-First Search Technique

This technique is an alternative approach to exhaustive search techniques such as depth-first and breadth-first method. In Best-First search method, at each level, forward motion proceeds from the node with most potential to that which leads to a goal or solution. Each time a node is created, the remaining distance to the goal is determined heuristically. This gradient measurement is used to determine the node that appears to be closest to a goal. That node is then expanded to determine its children nodes. If none of the resulting children is a goal, then they are evaluated heuristically to determine their remaining distance to a goal. The cycle then begins again by expanding the tree node on the bottom level with the greatest potential to lead to a solution. This is continued until the feasible solution is arrived at. The objective function for optimization can be voltage stability index or optimum loss in the distribution system. The objective function with voltage stability index is considered for the present work.

3.1 *Heuristic Tree Search Approach*

The primary objective is to develop a tree search technique that decreases the search space and still arrives at an optimal or near optimal solution. This is an effort for adding more intelligence to the search to reduce search space and computational burden. Through the use of heuristics, there is a possibility of determining a solution for a situation where by considering a branch of the tree as candidate for branch exchange that probably leads to a dead end without finding a solution. This aspect helps in reduction of computational exercise and saves time in arriving at optimum solution. The current operating configuration is chosen as the starting point from which to examine switching actions for two reasons. The minimal number of switching needs to be made to achieve acceptable configuration. The existing system is simplified by merging the intermediate buses between two buses where lateral branches out or a tie switch is present. By making this approximation, the number of vertices of the given tree reduces and makes the switching actions simpler. At each level branch exchange to be implemented is chosen to be the best one among all possible trees (children) that can be generated from the simplified spanning tree.

3.2 *Algorithm for Heuristic Search*

The algorithm for heuristic search is formulated as below:

(a) Choosing the current operating configuration as the starting point, a minimal spanning tree T^0 is determined.

(b) The system is simplified by merging the intermediate buses between the two buses where a lateral branches out or a tie switch is present.

(c) The load flow is performed on the simplified system and the approximate losses in the system are found.

(d) All the children of the simplified parent are examined.
For each open branch, a new candidate tree is found by (i) Identifying the loop.
(ii) Deciding on the branch to be removed.
For the candidate tree, the reduction in the objective function which is voltage stability ΔVSI is calculated.

(e) All the children with simplified parent tree are sorted using ΔVSI.

(f) The tree T^* is found with greatest $\Delta VSI > 0$ and satisfies feasibility constraints.

(g) If there is such a tree exists then choose T^* as T^0 and repeat from step (a) else terminate.

4. Neural Network Model

The neural networks provide artificial intelligence techniques for solution for engineering problems and being flexible in nature allows representation of many types of data for analysis. Since the training in based on the past as well as existing data of different parameters the results obtained can be more reliable. Also the computational difficulty is reduced by considerable extent and recent data can be obtained for further analysis. Thus it is appropriate to adopt the neural network technique for the load flow analysis and network reconfiguration, to ensure simplicity, reliability and flexibility in modelling process. In this paper a composite neural network approach is presented for operation of distribution systems. Also both statistics & heuristics are incorporated for predicting the load growth in small area within the distribution utility servicing area. The multi-layer feedforward neural network structure as shown in Figure 1 is used for implementation, and the back-propagation algorithm carries out training. The input parameters are chosen from historical data and the flexibility of processing the data is incorporated.

4.1 *Model for Training ANN*

Feeders in distribution system normally have mixture of types of loads, industrial, commercial, residential etc. The load daily load curves for the weekdays and the weekends form the basis of input data for training purpose. The architecture of the neural network is listed in Table 1. The neural network model can be implemented to take care of optimal operation of the distribution network at all times. From the simulation results it is found that many of the switches do not change their status hence named.as static switches. The switches change their states to achieve optimal configuration are called dynamic switches.

Table 1. Architecture of ANN

No. of Input Neurons	No. of Load types 'g'
No. of Output Neurons	No. of Dynamic Switches
Size of Training Matrix	[2gXn] where n is no. of time intervals

The application of ANN for load flow and network reconfiguration is bundled as "DISTFLOW" package. The developed package is tested foı sample test systems as well as practical system supplied by the power utility of the region. The past data pertaining to load duration curve and feeder ratings are considered.

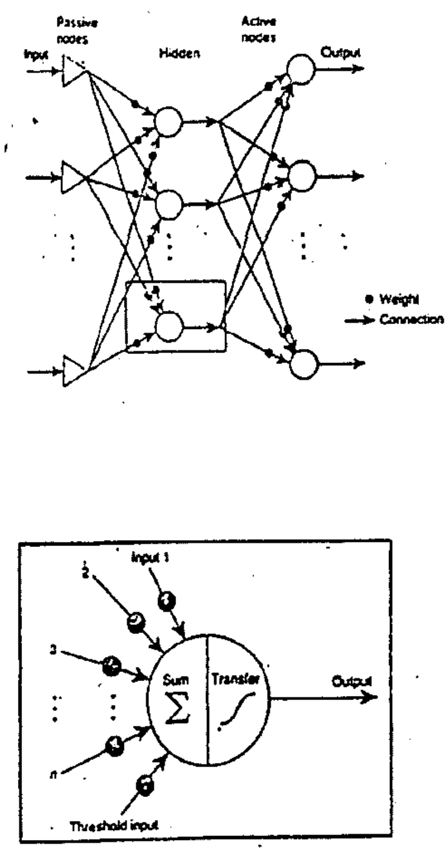


Figure. 1 : Structure of MLFFN

5. Optimum Compensation Level By G.A.

The optimal capacitor placement problem is a non-linear optimization problem and genetic algorithms (GA) are most suitable for such problems. The optimal locations are computed by index vector method and level of compensation is computed by GA.. The design variables are the size of capacitors to be placed at a selected location and the resultant saving in the loss charges. A string length of 20, population of 50, crossover probability of 0.6 and mutation probability of 0.001 is adopted. The inclusion of the GA approach improves the performance of the network.

6. Scheme for System Operation

(a) System data is given as input to off-line simulation.
(b) Static and dynamic switches are determined .
(c) The daily load curve of the system is procured.
(d) Neural network training is carried out by using the developed package 'DISTFLOW'.
(e) The testing of trained network is done for other random inputs to get new switching configuration.
(f) Critical buses are identified for compensation and optimum capacity of compensation is determined using genetic algorithms.

7. Case Studies and Results

The proposed method is applied to the service area of the power utility. The study is done based on (i) best network configuration (ii) optimal compensation level on highest priority feeder. The proposed approach is implemented on practical system of utility service area covering N.I.T.K, Surathkal. The Mangalore electricity supply company is the utility authority. The 33/11 KV, 5 MVA distribution substation is located at Surathkal and has 4 feeders running from the substation comprising of total 140 buses. The daily load curve of all the feeders is considered for the input data for the neural network model. It is observed that there is no possibility of restructuring of feeder no. 1 in the network. Hence remaining 3 feeders are considered and the simplified schematic diagram indicating tie switches is shown in Figure 2. The sectionalising and tie switches are identified with off-line simulation as listed in Table 2. The results of the off-line simulation and voltage stability index are given in Table 3. The neural network model is trained with these results and then it is tested for arbitrary input vector from the daily load curve in order to arrive at the better reconfiguration scheme as shown in Table 4. The optimum configuration arrived will be the best choice

Table 2. Switch Groups

Type of Switches	Switch Numbers
Static Switches	S5,S6,S21,S37,S38,S54,S59,S83, S89,S93,S121,S133,S140
Dynamic Switches	S4,S11
Tie Switches	T1,T2

Table 3. VSI Computation Results

Time (Hrs)	Output of Off-line Simulation				VSI
	S4	S11	T1	T2	
03	0	0	1	1	0.065
08	0	1	1	0	0.053
13	0	0	1	1	0.067
16	1	1	0	0	0.042

Table 4. Neural Network Model Output

Time (Hrs)	Output of ANN Model			
	S4	S11	T1	T2
03	0	0	1.00	1.0000
08	0.001	1.0007	1.001	0.0006
13	0	0.0005	1.002	0.9996
16	1.000	1.0007	0.001	0.0001

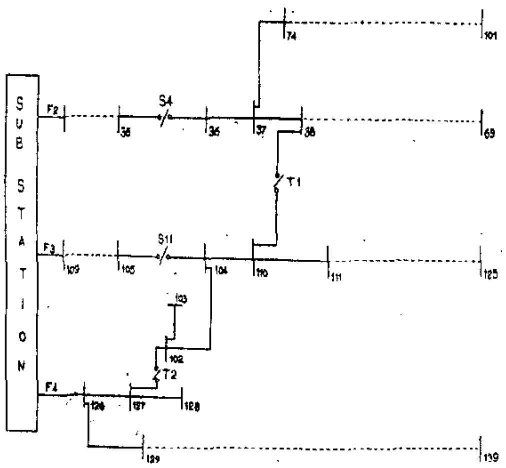


Figure 2 : Tie-Switch Interconnections

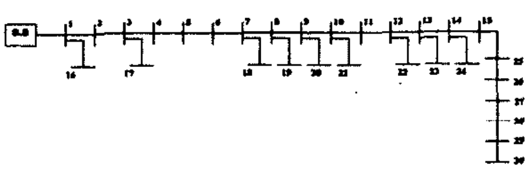


Figure 3: NITK Feeder Structure

The feeder 2 is a critical feeder carrying high priority loads of which the National Institute of Technology Karnataka (NITK) installation is a major load. Hence during the simulation process highest priority is given for this feeder to get good quality of power. The optimum compensation level is determined by the application of index vector method and genetic algorithms. For convenience, the feeder 2 buses are renumbered from 1 to 30 as shown in Figure 3.

8. CONCLUSIONS

The performance of the electrical system can be improved by efficient and reliable distribution network. This paper discusses a neural network technique for network restructuring in distribution automation systems. The classification of loads, their variation in load curve are considered to be input for training the ANN and optimum feeder configuration is arrived at. The operation is optimised by providing compensation at critical buses as determined by genetic algorithms. The approach is implemented for 140 bus practical system belonging to service area of Surathkal city subdivision of power utility authority MESCOM, Karnataka state.

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