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Research paper

Distribution system reliability enhancement by using grid upgrading technology

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Abstract

Losses are essential threat to power system reliability and worthiness; such disturbances are raised form generation plants until destination and end users. Power loss due to load variation is studied in this paper when radial distribution system is considerable; load is arranging among feed-forward nodes and hence losses may be developed due to overload in any particular node. As the radial system is involved, any changing of network topology yields a noticeable improvement on reliability. More topologies are resulted by changing the feeder switching status. IEEE 16 bus-bar radially structured distribution grid is investigated using Matlab software. Results shown that optimum reliability is achieved when node 2, node 4 and node 15 are closed. So far this topology is active, power loss is minimized and voltage profile is improved as compared to seven iterations of different topologies.

Keywords: *Per-Unit; BWFW; Reliability; Losses; Reactive Power; Active Power; IEEE; Radial Structure; Voltage Profile; ANN.*

1. Introduction

Power systems in general are attributed by their ability to generate the required energy and to successfully deliver of that energy to the consumers. The means which are adopted by such systems to carry the power across diversity of lands are known as distribution systems. This section of power system is quite essential and effective to ensure successful delivery of power to consumers [1]. Ideally, the effective distribution system is termed by loss less system where same generated energy is ensured to the consumers with zero losses; such assumption seems non-practical as impedance lying on each distributor and hence power cannot transport without loses [2]. Actually, the losses minimization is very interested argument in power engineering so that a plenty of researches are made to reduce the power losses. Twelve presents of generated power are faded away in distribution system [3]. Attention was given in this project to the methods that in turn minimizing the power losses in distribution system. Distribution of electrical power is usually taking place under the said "distribution systems"; the same is considered as final level of power stages that ensures a safe delivery of the said electricity to the consumers. [4] Loads or consumers are interfaced on the terminals of power distribution system and can be:

- Residential places such as apartments, row-houses and residential premises.
- Commercial places such as hotels, restaurants, companies or schools.
- Industrial consumers such as factories and manufacturing premises.

Above categories are made under the fact of consumption of electrical unites (unites systems). Moreover, it can be used to study the power system behaviours from the consumer prospective. In other word, residential places are seemed to operate at all times (24 X 7) whereas the companies and schools are remained operational during working hours of that particulars organization; so, it can be said that bus bar where the residential loads are connected in higher portion of its load are expected to be in high demand, similarly this fact can be applied for the rest categories of consumers. Many researches were conducted to improve the performance of power in distribution system; author at [5] mentioned that: losses can be minimized at fault occurrence by changing the switching status of feeder, especially when fault located at intermediate feeder so all under bus-bars will be not functioning in case of fault. Furthermore, authors in [6] [7] have made statement that power system performance enhancement is function of two arguments: voltage profile in feeder and power losses. Essentially, power loss has to minimum and voltage has to maximum.

In this paper, we proposed a far less expensive method to improve the voltage profile and minimize the losses by using artificial neural network for searching the possible paths and ensure radial structure in the resultant network after switch upgrading technology. ANN will find the applicable nodes to participate the switch updating process, it is important to denote that calculations made in per units (PU).

2. Distribution topologies

As stated in above, distribution system is responsible to compete the environmental and physical challenges which resist the power flowing in transmission line and resulting in form of losses. Every distribution system is basically consisting of transmission lines, nodes/bus bars and transformers. Moreover, distribution system may adopt devices to perform specific task such reactive power injection, power factor correction, STATCOM etc. in this article, two types of distribution system are explained as follow:

2.1. Ring distribution

This As shown in Figure 1, the ring distribution as name indicating is taking a shape of closed ring (power is distributed in loops) where the power from generation unites are shared by many feeders, usually, it is used for tying the main feeders of high voltage together. It costs higher than radial system as more nodes and switches along with their protection devices are involved.

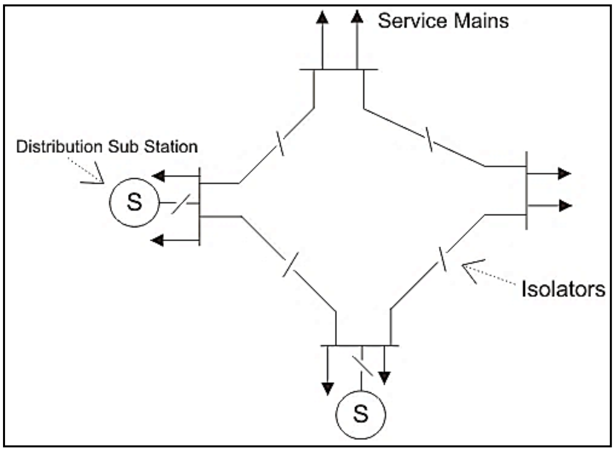

Fig. 1: Ring Distribution System Network Structure [1].

2.2. Radial distribution

Unlike ring distribution system, radial system is another form of distribution that connecting multiple nodes with sub-station where each node is supplied with power from single feeder; Figure. 2 is depicting of this system and it is cleared that a central node is entitled with root node is radiating of power from upper unites (generation/substations) to lower nodes. Every node is connected to serve particular geographical area with electricity and at the same time it is connecting the coming nodes. In such form of distribution system, each node is getting supplied by another node in the network and nodes in turn are serving the loads connected on their terminals (consumers).

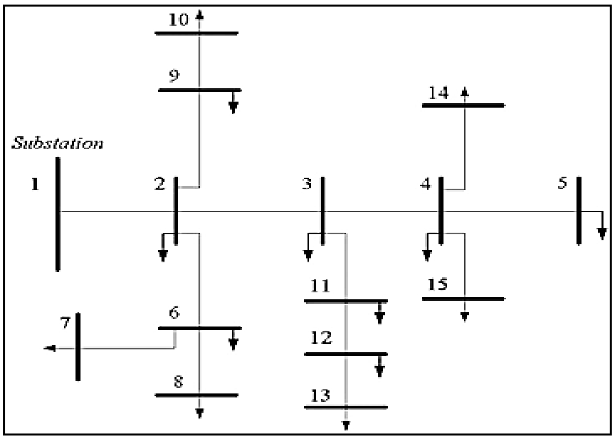

Fig. 2: Radial Structure of Distribution System [1].

While simulation, it is important to maintain the following constrains for radial network:

a) No loop is developed when network is on operational mood: each bas bar is provided with power from one end (input), bus bar should divert of received power into the load connected on same bas bar and the rest portion of power must be provided to the next bus bar so that power is ensured to not propagate in backward.
b) Each bus bar is provided with power from single feeder: node is generated for one time from one feeder; in case of multiple feeders are serving of this particular node then one of them should be tripped off.
c) The power delivered to any bas bar should be limited to consumption budget: power fed to this node must be enough to serve loads on bas bar terminals as well as load of next bas bar if any.

As Figure 2 depicts; it is mandatory for assuring the radial structure that one or more node is not feeding any other node in the system.

3. Mathematical modeling

Aa For the sample network of Figure 3; three bus bars are representing the feeder and load busses. By applying of Backward-Forward method, the current and voltage in every bus and branch are determined.

Backward sweep: Using of KCL:

I tl2=I node (3)

I node (3) = (S node (3))/ (V node (3))

I tl2= (S node (3))/ (V node (3))

I tl1=I node (2) + I tl2

I tl1=I node (2) + (S node (3))/ (V node (3)) (1)

For above I tl1 and I tl2 is achieved by considering the initial voltage in each bus bar with unity value. By the end of this, the backward sweep is over.

Forward sweep: in this section of analysis, the voltage in each node is updated with by help of calculated currents from backward sweep.

$$\mathrm{V\ node\ (2)} = \mathrm{V\ node\ (1)} - \left(\mathrm{I\ tl1} * \mathrm{Z(tl1)}\right) \quad (2)$$

Generally, the equation can be reformed as:

$$\mathrm{V\ node(n)} = \mathrm{V\ node\ (n-1)} - (\mathrm{I\ tl(n-1)} * \mathrm{Z(tl\ n-1)}) \quad (3)$$

$$\mathrm{Pl\ (tln)} = \mathrm{I}^2\mathrm{(tln)} * \mathrm{R\ (\ tln)} \quad (4)$$

Where n= {1, 2, 3…. K}, k<∞

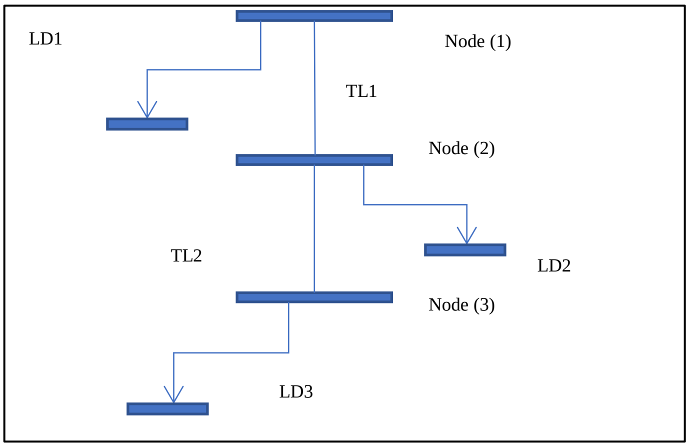

Fig. 3: Simple Load Flow Topology.

$$\mathrm{Z\ (tln)} = \mathrm{R\ (tln)} + \mathrm{j\ X(tln)} \quad (5)$$

$$\mathrm{R\ (tln)} = \mathrm{Real\ [Z(tln)]} \quad (6)$$

Knowing that: “PL” line losses due to heat “R” the resistor which is the real part of line impendence. Finally, the losses can be estimated in whole by mathematical summation of all lines losses in the distribution system so we can write the following formula:

$$\mathrm{PLT} = \sum_{\mathrm{tln=1}}^{\mathrm{tln=k}} \mathrm{Pl\ (tln)} \quad (7)$$

Where, "k" stands for the maximum number of lines separating the bus-bars (nodes) in radial system. The load flow algorithm is then implemented by software using Matlab to perform the analysis in quick and flexible fashion. The Figure 4 is depicting the steps of coding the above method in software. The below mentioned steps are used for identifying the system losses using backward and forward sweep method. This procedure is repeated for all possible topologies of the network.
The process may begin for reliability assessment of network in ordinary configuration without applying of any switching operations. Similarly, program will work side by side with reconfiguration algorithm to assess the performance which can be evaluated base on reliability parameters. In this project; the term reliability is attributed to the minimum losses in optimum node voltage. Ultimately, the program will suggest the results of lower losses configuration (topology) that yield maximum bus voltage amongst available networks. The networks to be judged are produced by the artificial neural network program.

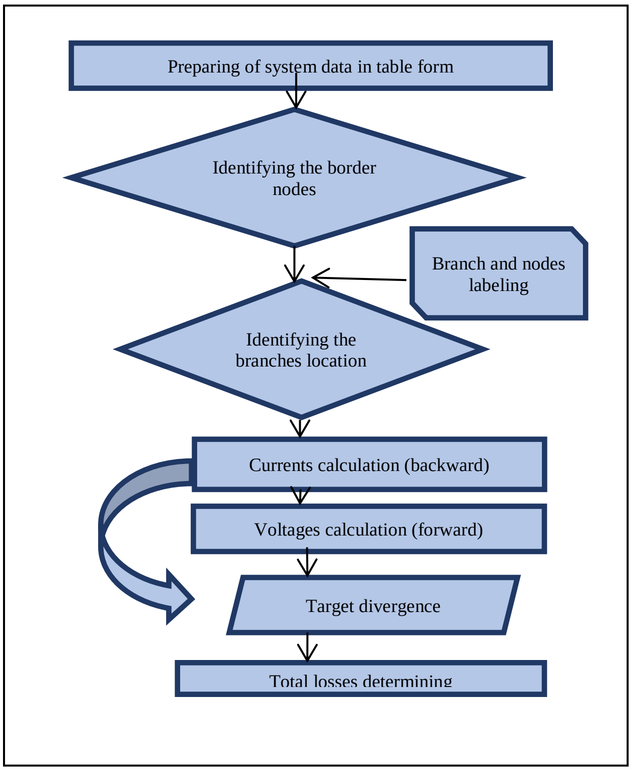

Fig. 4: Load Flow Calculation Procedure.

4. ANN Configuration

In Matlab, ANN application can be started by "newff" command to create "supervised learning model". This model is expected to find the possible topology of IEEE radial distribution system. The possible inputs are formed as matrix of (16 by 8) dimension which stands for the power limits in each node; the artificial neural network model is trained to make the proper path for such input where the same can form the distribution system with predefined constrains. System is created with sixteen nodes so that artificial neural network has implemented with sixteen nodes of input layer and sixteen nodes for output layer. The approximation function that used while constructing of this model is selected as "minmax". Model parameters can be described as follow:

a) Layers creation: two layers were made, each of sixteen nodes where every node is connected with each other by neuron. The proper decision of this model can be achieved by exact diversion of data from input layer to output layer through the middle layer of hidden nodes. The hidden layer is performing the required approximation to achieve the desired output.
b) Approximation function: for successfully responding to the data on input layer, approximation was done by using "minmax" function. However, the input matrix is divided in columns fashions and then approximation is taken place using the above function.
c) Inter layer processing (first): data is manipulated within each layer i.e. input layer and output layer; hence another two types of processing are applied. During the data residence in first layer, it got approximation by "tansig" function where tangent transfer function is return the data in from of -1 and +1 only.
d) Inter layer processing (second): on the output layer, the data was converted into -1, +1 form and pre-approximated by minmax transfer function so that finally a the output layer another transfer function as applied to linearate the data in the best possible accuracy; however "purelin" transfer function is used.
e) Training: input is trained with the right target to act so while next processing. "Trainlm" was used for this purpose.
f) Final result: the implemented neural network is become ready to give the expected results. So, the command "sim" can be used to call the input into network. The process is required a proper definition of some parameters as in table 1. However, the performance of this model is depicted in Figure. 5.

Table 1: ANN Optimum Configuration

Parameters	Values
Error rate	5 e (-3)
Maximum epochs	1 e (3)
Training iterations	50
Training goal	0

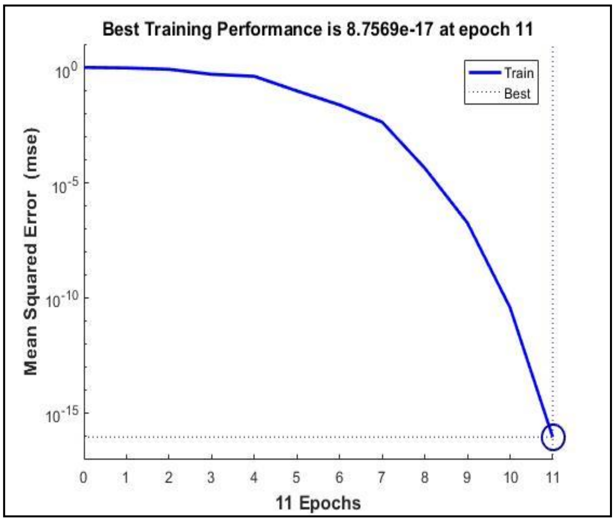

Fig. 5: ANN Performance Measure.

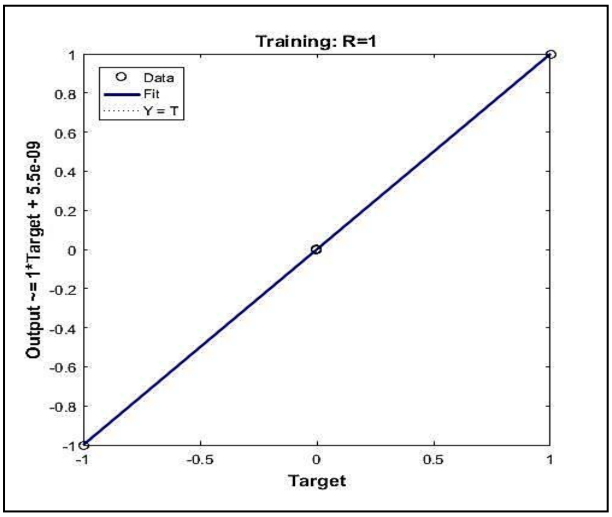

Fig. 6: The Regression Process of the Resulted Training.

5. System architecture

IEEE radial distribution system, sixteen bus-bars, 100 MVA and 23 KV is selected to study under various assumptions and operation criteria. Table 2 is depicting the system configuration at basic form.

Table 2: IEEE 16 Nodes System Information

Serial Number	Receiving Bus-Bar	Sending Bus-Bar	Line Resistance	Line Reactance	Switch Number
1	16	7	0.0900	0.12000	16
2	14	10	0.0400	0.04000	15
3	11	5	0.0400	0.04000	14
4	16	15	0.0400	0.04000	13
5	15	13	0.0800	0.11000	12
6	14	13	0.0900	0.12000	11
7	13	3	0.1100	0.11000	10
8	12	9	0.0800	0.11000	09
9	11	9	0.1100	0.11000	08
10	10	8	0.1100	0.11000	07
11	9	8	0.0800	0.11000	06
12	8	2	0.1100	0.11000	05
13	7	6	0.0400	0.04000	04
14	6	4	0.0900	0.18000	03
15	5	4	0.0800	0.11000	02
16	4	1	0.07500	0.10000	01

The location of each switch that tabulated in table 2 was mentioned earlier in table 1; for example, switch number 5 is lying between node 8 and node 2 and switch number 4 is lying between node 7 and 6.

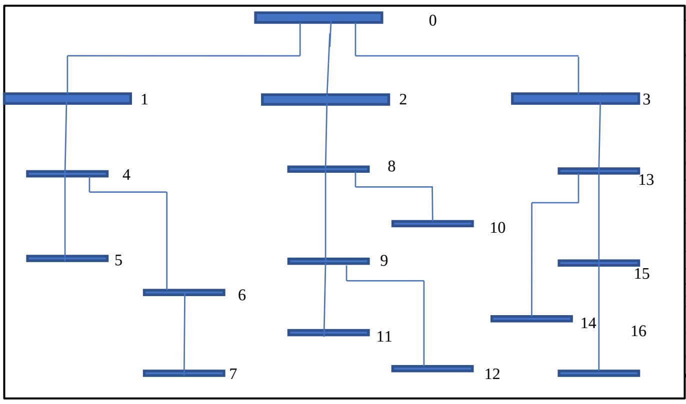

Fig. 7: The Initial Structure of Radial System.

Table 3: Switching Status in Radial Groups as Per the Ordinary Structure

Switch Number	Status	Coding identity
01	Permanent closed	1
02	Normally closed	-1
03	Permanent closed	1
04	Normally closed	-1
05	Permanent closed	1
06	Permanent closed	1
07	Normally closed	-1
08	Normally closed	-1
09	Permanent closed	1
10	Permanent closed	1
11	Normally closed	-1
12	Permanent closed	1
13	Normally closed	-1
14	Normally opened	0
15	Normally opened	0
16	Normally opened	0

However, looking to the ordinary structure of this selected system i.e. IEEE 16 buses radial distribution system, the table of above mentioned switches can be implemented and so it carries the initial status of each switch in the system, moreover, the network of table 3 is depicted in Figure 7.

6. Case study

According to the target of ANN program and sticking on the criteria of radial system assurance which are given in preceding section, seven cases are selected for study where each is about new topology derived from Figure 7 and representing a particular event which may exist within distribution system. In below we can state the reconfiguration resulted from ANN program, refer table 3 for switches status.

- When switches (7, 8 and 16) are opened.
- Switches (4, 7 and 14) are kept opened.
- Opening the switches (8, 11 and 16)
- Opening the switches (2, 4 and 15)
- Switches (4, 7 and 14) are opened
- Switches of (2, 4 and 11) are kept opened

7. Results and discussion

Reasons behind this reconfiguration can be either for removing unwanted occurrence such as fault at any bus-bar or it can be done to distribute the network load from loaded bus to light loaded bus; network criteria should be obeyed and that can be seen in all topologies resulted from reconfiguration program; radial system is assured for each case. However, losses of each node were calculated based on the subtraction of line losses (switches losses) from the total provided power of this node. As power burst from generation node to the coming node connected with it by particular line, losses are developed in that line and the magnitude of this losses is depending on transmission line length and other physical environmental parameters such as weather conditions and material used to fabricate the line. However, another issues such as load is also considered as reason behind losses development in transmission line; load connected to any node is required power in sufficient value to prevent losses; so, system reconfiguration was done randomly using ANN program to provide the possibilities that comply the conditions of predefined database and above cases have generated.

Mathematical summation of losses in each node within every case is yielding single value called total power losses; Figure 8 is depicting this value for total eight cases. It is clearly seen that case number five is holding the minimum losses, in this iteration the switches (2, 4 and 15) were opened and all other switches were closed.

The maximum losses are laid on case one when switches 7, 8 and 16 were opened and all others were closed. However, voltage profile recorded and represent the per unit voltage of node, however, in order to simplify the statistical presentation, the average value of voltages is calculated in reach iteration as depicted in Figure 9. Optimum voltage is found at iteration number five (fourth case study).

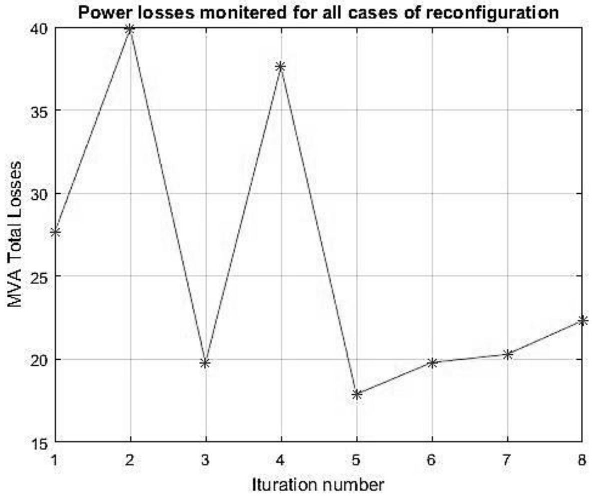

Fig. 8: Total Power Losses in All Iterations.

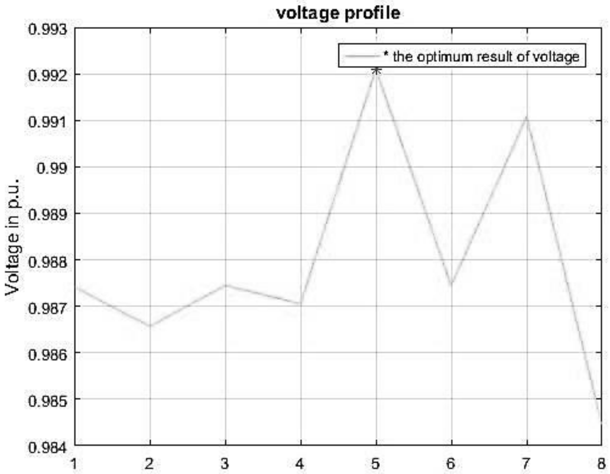

Fig. 9: Voltage Profile for All Cases.

8. Conclusion

In this article, Project was included detailed study that aiming to improve the reliability of distribution system; it was also cleared that power losses in distributors is considered as fundamental even that may threat the system reliably. In order to treat the problem, a reconfiguration protocol is one of feasible solutions, it simply implied, searching the lesser losses path from generation end to consumer end. System analysis was carried out on IEEE sixteen bus radial distribution system; procedure is started by examining the standard topology of system without applying any change hence, power supplied to each node is identified and base of current summation load flow method (backward forward sweeps) power losses are determined in each branch of network. The branches are been defined by two or more nodes coordination so that each couple of nodes is forming one branch, this can be considered as distribution line where power losses is developed. After the test of losses, voltage profile in every node is then calculated and by this reliability assessment study for standard topology of IEEE system is yielded.

Following procedure is devoted to implement multiple topologies from the mother system, this idea is implemented to reconfigure the system in efforts to minimize the path losses and maximize if bus voltage. Artificial Neural Network is deployed to predict the possible paths which are obeying to this system constrains.

Reliability assessment is also initiated for every possible topology and results were recorded. System is implemented in software using Matlab and results are found much consistence. Among of eight different topologies that called by program, it was seen that iteration two is yielded the worse result of performance and attempt of fifth iteration is yielded the best result of performance. System is examined under various topologies and it was found that in optimum reconfiguration the power required to be generated from the plant end is reduced. This topology can be considered as more economical worth that others including the standard system prior to apply any configuration.

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