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Minimization Of LossesIn Radial DistributionSystem UsingNetwork Reconfiguration

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Abstract- This paper presents a solution technique of solving network reconfiguration problem with the aim of minimizing Real power losses of the system for an explicit set of loads. Amongst reasonably a lot of performance standards considered for optimal network reconfiguration, voltage constraint is a significant one. This problem calls for the determination of the best combination of feeders to be opened in the Radial Distribution system (RDS) so that the resultant RDS provides the optimal performance in the preferred settings. In answering this problem, a new optimization technique called as Dijkstra Algorithm (DA) is used to reconfigure the RDS. DA follows an unique pattern for sustaining the radial nature of the network at every stage of the solution. The anticipated scheme minimizes the objective function which has been given in the problem formulation so as to reduce the I^2R losses in addition to balancing of loads in the feeders. The solution method includes determination of the best switching combinations and calculation of power loss and voltage profile. The practicality of the anticipated technique is confirmed in an IEEE standard Test distribution network, where the results obtained are compared by means of available literatures. Correspondingly it has been observed from the results that the network losses are reduced when the voltage stability is improved through the network reconfiguration.

Keywords- 33 Bus RDS, Dijkstra Algorithm, Network Reconfiguration, Radial Distribution System (RDS), Reactive Power, Real Power Losses, Voltage Magnitude

NOMENCLATURE

V_j	=	Voltage magnitude of the j^{th} bus
P_j	=	Real power injection at the jth bus
Q_j	=	Reactive power injection at the j^{th} bus
δ_j	=	Phase angle at the j^{th} bus
P_{acc}	=	Real power accumulated
Q_{acc}	=	Reactive power accumulated

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$P_{ij(loss)}$	=	Real power loss in the line connecting i^{th} and j^{th} bus
NVB	=	Number of buses that violate the recommended voltage limits
V_L	=	Upper limit of the i^{th} load bus
V_i	=	Voltage magnitude of bus i
V_{min}	=	Minimum Voltage Limit
V_{max}	=	Maximum Voltage Limit
P_i	=	Real power load demand in the bus i
Q_i	=	Reactive power load demand in the bus i
R_{ij}	=	Resistance in the line connecting the i^{th} and j^{th} bus
VDI	=	Voltage Deviation Index

1 INTRODUCTION

Distribution systems are usually designed radially and there are two categories of switches typically found in the system intended for both protection and configuration management. These are called closed and open switches. Closed ones are called as sectionalizing switches and the Open ones are termed as tie switches. Radial Distribution system (RDS) involves different types of loads like industrial, commercial, domestic etc., The demand profile of these loads may possibly vary from time to time and perhaps will root imbalance power flow in the feeder and could lead to the menace of voltage collapse owing to low voltages.One of the ways and means to sustain the safety and reliability of the system is the Reconfiguration of RDS. This alteration of the network topology is done by means of altering the status of the open and closed switches. When scheduling the network reconfiguration, demand profile of different consumers are considered to notice if a particular configuration is safe, reliable & has adequate capacity to supply all the customers. Once the Feeder reconfiguration is done, overburdening of the feeder is reduced, I^2R loss is minimized, voltage profile of the system is improved thereby leads to voltage stability enhancement.

B. Venkatesh and RakeshRanjan [1] presented a solution technique which uses fuzzy and adaptation of evolutionary programming (FEP). This method comes handy while considering optimization of multiple objectives. N. C. Sahoo and K.Prasad [2] advanced the alteration of network topology using a Fuzzy Genetic Approach (FGA) in order to maximize the voltage stability of the network. FGA practices an apt coding and decoding scheme for sustaining the radial nature of the network at every stage of genetic evolution besides using a fuzzy rule centered mutation controller for efficient search of the solution space. Ahmed R. Abul'Wafa [3] described a load flow based on graph theory where the developed load flow algorithm has been integrated into a new heuristic search methodology for finding the minimum loss configured network. M. A. Kashem et al., [4] proposed a branch loss-change technique where they derived a loss-change formula to determine the change of losses in the system when a branch exchange is performed. The best branch exchange to be implemented is chosen at each successive operation that gives a maximum loss reduction without any constraints being violated. There are many a ways of handling a heuristic algorithm based on the modification or adaptation of the algorithm. The authors [5] [6] [7] used heuristic algorithms for the reconfiguration problem in order to achieve the least I^2R loss in the network. But the algorithm is called heuristic until the best solution is proven to be the best. H. Nasiraghdam and S. Jadid [8] introduced a fresh Multi-Objective Artificial Bee Colony (MOABC) algorithm to explain RDS reconfiguration and hybrid (photo voltaic/wind turbine/fuel cell) energy system sizing. MOABC outlines a potential solution for the optimization problem as a food source, and the fitness value of the solution as the nectar amount of the allied food source. Anil Swarnkar et al., [9] stretched a method, centered on Adapted Ant Colony Optimization (AACO) for the reconfiguration of RDS. AACO overcomes the drawbacks of conventional ant colony optimization technique by encoding the discrete ant by means of the graph theory.

J. S. Savier and Debapriya Das [10] discussed the impact of network reconfiguration on loss allocation based on fuzzy multi objective approach. The authors have considered loss allocation and network reconfiguration together in which the loss allocation is by the quadratic loss allocation pattern and the network reconfiguration is framed using fuzzy multi objective problem. M. A. Kashemet al., [11] stated a geometrical approach for loss minimization in which each loop in a network is represented as a circle, which is again derived from the relationship between the change of loss due to the branch-exchange and the power-flows in the branches.Rayapudi Srinivasa Rao et al., [12] prescribed a newly developed technique to find the optimal switching status of the reconfigured RDS which is conceptualized using the musical process of searching for an impeccable state of harmony. The algorithm is called Harmony Search Algorithm (HSA). HSA practices a stochastic random search as an alternative of a gradient search which removes the necessity of derivative information.Almoataz Y. Abdelaziz et al., [19] projected "real ant-behaviour-inspired" ant colony optimization implemented in the hyper cube framework and the "musician behavior-inspired" harmony search algorithm to address the objective function. Yuan-Kang Wu et al., [20] minimized the power loss in RDS by network reconfiguration in the presence of Distributed Generators. He used Ant colony Algorithm (ACA) to do so. K.K.Li et al., [21] recommended Tabu Search (TS) approach to obtain the near-optimal solutions of combinatorial optimization problems, which makes it appropriate to resolve the problem of RDS reconfiguration.

In the light of the above progresses, this paper presents an optimization technique called Dijkstra Algorithm (DA), which has been developed as the solution technique for feeder reconfiguration. The application of DA for minimization of Real power losses due to network reconfiguration is formulated as an objective problem subject to operational and electric constraints. A load flow program was developed and the algorithm based on [13] is used to compute the power flow. Then it is integrated into DA for determining the minimum loss RDS configuration. The distribution network presented by Baran and Wu [14] is used to demonstrate the reliability and efficacy of the proposed algorithm.

This paper is organized as follows: Section 2 describes the load flow. Section 3 delivers the mathematical model of the problem. Dijkstra Algorithm (DA) and its ability to solve the optimization problem are discussed in Section 4. Test system and the result analysis are done in the sections 5 and section 6 respectively. And finally this paper is concluded in Section 7.

2 LOAD FLOW

To meet the present emerging domestic, industrial and commercial load day by day, effective forecasting of the RDS is essential. To ensure the effective planning with load transferring, the load flow study of RDS becomes utmost significant. Load flow analysis is concerned with describing the operating state of an entire power system. Newton Raphson and Fast decoupled load flow solution techniques are used to solve well- behaved power system. However these are in general unsuitable for solving load flow for RDS because of their low X/R ratios of branches.

A section of RDS has a sending end bus (i[th] bus) and receiving end bus (j[th] bus). The line in connection with these two sections has an impedance$(Z = r + jx)$. The power flow through this line can be in both directions. The power flow at the sending end bus$(S_i = P_i + jQ_i)$is different from the power flow at the receiving end bus$\left(S_j = P_j + jQ_j\right)$.

A load flow algorithm [13] solves the power balance equations at all buses and finds the corresponding voltage solution. At load buses, the load flow algorithm will solve for the bus voltage magnitude and phase angle. The known parameters at a load bus are the received real and reactive powers. Hence a load flow must solve for the bus voltage magnitude in (1) and phase angle, (2).

$$V_j^2 = -\left[rP_j + xQ_j - \frac{V_i^2}{2}\right] + \sqrt{\left(rP_j + xQ_j - \frac{V_i^2}{2}\right)^2 - [r^2 + x^2]\left[P_j^2 + Q_j^2\right]} \quad (1)$$

$\delta_j = \delta_i - \sin^{-1}\left(\frac{xP_j - rQ_j}{V_i V_j}\right)$(2)

If the voltage magnitude and phase angle values are to be computed for the receiving end bus, the only variables needed are the receiving end bus real and reactive power values, the sending end bus voltage magnitude and phase angle value, and the value of the line impedance connecting the two buses. All the values needed for the load bus calculations are easily attainable in practice.

2.1 Load Flow Algorithmic steps

Step 1 : Read System data structure.$Q_{T,loss} = \sum_{i=1}^{n} Q_{ij(loss)}$

Step 2 : Goto Slack bus.

Step 3 : Initialize $P_{acc} = 0$ and $Q_{acc} = 0$

Step 4 : Calculate P and Q for all buses

Step 5 : CalculateV_j and $\delta_j$for all buses using equations (1) and (2)

Step 6 : DetermineP_{loss} and $Q_{loss}$for all lines

Step 7 : Update P_{acc} and Q_{acc}using the formula

$$P_{acc} = P_{loss} + P_j \; ; Q_{acc} = Q_{loss} + Q_j$$

Step 8 : Goto Next bus and reprise the step from 4 to 8 up until Last bus is reached.

Step 9 : Check for convergence, (3) and print the result, else goto step 2.

2.1.1 Convergence Criteria

In this Load Flow [13], it is checked whether the sum of powers flowing out of the lines connected to each bus equals (or equals within a tolerable limit) the net power injected into that bus. Mathematically, convergence criteria for the presented load flow is given in (3)

$$(PG_i - PD_i) - \left[\sum_j \left(V_i V_j Y_{ij} cos(\delta_i - \delta_j - \theta_{ij})\right)\right] \le \varepsilon$$

$$(QG_i - QD_i) - \left[\sum_j \left(V_i V_j Y_{ij} sin(\delta_i - \delta_j - \theta_{ij})\right)\right] \le \varepsilon \qquad (3)$$

3 MATHEMATICAL PROBLEM STATEMENT

3.1 Total Real and Reactive power loss

The real & reactive power loss in the line connecting ith and jth bus is given by,

$$p_{ij(loss)} = \frac{[P_j]^2 + [Q_j]^2}{[V_j]^2} * R_{ij} \qquad (4)$$

$$Q_{ij(loss)} = \frac{[P_j]^2 + [Q_j]^2}{[V_j]^2} * X_{ij} \qquad (5)$$

The Total real& reactive power loss of RDS having ‘n’ buses and ‘n-1’ branches is given by,

$$P_{T,loss} = \sum_{i=1}^{n} P_{ij(loss)} \qquad (6)$$

$$Q_{T,loss} = \sum_{i=1}^{n} Q_{ij(loss)} \qquad (7)$$

3.2 Voltage Deviation Index (VDI)

The Voltage Deviation Index [1] is calculated using the formula,

$$VDI = \sqrt{\frac{\sum_{i=1}^{NVB}(V_{Li} - V_L)^2}{N}} \qquad (8)$$

To enumerate the degree of violation of limits imposed on voltages at buses in a RDS, VDI is well-defined where NVB is the number of buses that violate the recommended voltage limits and V_L is the upper limit of the ith load bus. In the course of reconfiguration, if the state of the system has voltage limit violations, the anticipated solution must try and lessen the index VDI. When a branch is switched on and another is switched out in a loop, the solution space is no longer continuous. The variable that defines the status of a branch as to whether it is switched in/out adopts discrete states of zero or one. Owing to the discontinuous and discrete nature of the problem, classical techniques are rendered inappropriate and the practice of global search techniques is essential.

3.3Objective function for network reconfiguration in RDS

The objective is to minimize the I^2R losses in RDS and thereby the voltage profile of the system is enhanced. This is attained by finding out the best set of branches to be switched out such that the subsequent RDS experiences least I^2R loss and has the best voltage profile.
The mathematical model of the problem can be expressed by the following expression.

$$\text{Minimize } f = \sum_{i=1}^{n} P_{ij(loss)} + \sqrt{\frac{\sum_{i=1}^{NVB}(V_{Li} - V_L)^2}{N}} \qquad (9)$$

Subject to,

$$V_{min} \le |V_i| \le V_{max}$$

The first term in the (9) represents the total I^2R loss in the system and the second term denotes Voltage deviation index (VDI).

4 DIJKSTRA ALGORITHM

The basic idea of DA is to explore the shortest path [Fig.1] from source point (labeled as s) to outside gradually. In execution process assign a number to each point (called the label of this point), which expresses the weight of the shortest path from s to this point (named as P label) or upper bound of the weight of the shortest path from s to this point(named as T label). In each step, modify T label, and alter the point with T label to point with P label, so that the number of vertex with P label in graph G increases one, then we can obtain the shortest path from s to each point only by n-1 steps (n is the number of vertexes in graph G). In order to optimize the algorithm, here we express DA in another way. Suppose each point has a pair of label (dj□pj). dj is the length of the shortest path from the starting point s to the end point j, and pj is the front point of j in the shortest path from s to j. The basic process of solving the shortest path algorithm from the starting point s to point j is described as follows:

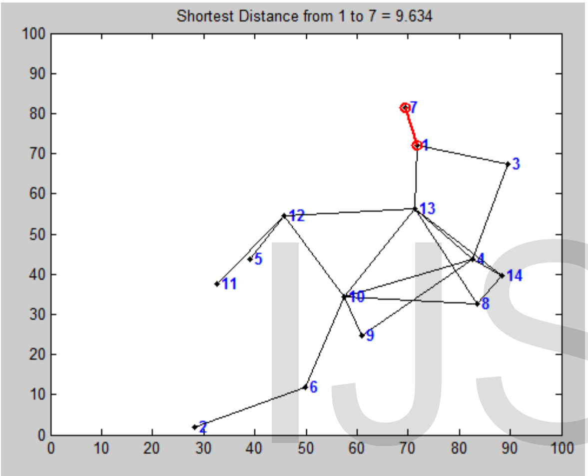

Fig. 1: Shortest Distance- search space for 33 Bus system

(1) Initialization.

Set the starting point as: □ds=0, ps is null; □all other points: di=∞, pi=?; □mark the starting point s as k=s and all other points as unlabeled.

(2) Examine the distance between the marked point k and unlabeled point j that is directly connected to k. Set dj=min[dj□dk+lkj], lkj is direct connection distance between k and j.

(3) Choose the next point. Choose the smallest i in di from all unlabeled points: if di=min[dj, all unlabeled point j], then i is selected as one point of the shortest path and set as marked.

(4) Find the front point of i. Find j connected directly to i from marked points, make it as front point and set pi=j.

(5) Mark i. If the target point has been marked or all points have been marked, then the algorithm is finished, otherwise set k=i and turn back to step (2) to continue. As can be seen from above, in the process of achieving DA, the core step is to choose an arc with the shortest weight from unlabeled points. This is a cyclic comparing process. If the unlabeled points are stored in a linked list or array in unordered form, we have to scan all the points to choose an arc with the shortest weight. It will affect computing speed in the case of large amount of data.

5 TEST SYSTEM

5.1. 33 Bus Test System

The Line loss minimization by reconfiguration is executed in a 33 bus RDS (Fig 2) and the load data are given in [12]. The test system consists of 33 Bus, 32 Lines and 5 Tie switches. The first bus is considered as the substation bus. Loads are connected to all buses except the first bus which is the substation bus. The total real power load and reactive power load of this test system are 3715 kW and 2300 kVAR respectively. The substation voltage is 12.66 kV.

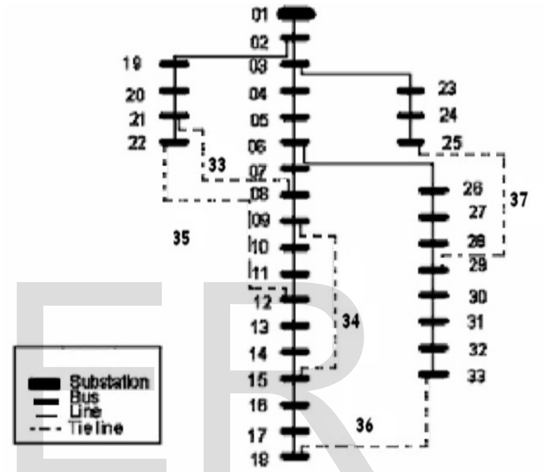

Fig. 2: Line diagram of 33 bus RDS

6 RESULT ANALYSIS

The results of 33 bus test system are given. The program is coded in MATLAB software. Before reconfiguration, the tie switches *s33, s34, s35, s36, s37* are kept open. For the given total real power load of 3715 kW, the Line loss is obtained as 202.418 kW in the base case. The minimum voltage is registered as 0.9237 p.u at the 18th bus. The optimal network configuration for loss reduction is achieved after applying the DA algorithm, when the tie switches *s33, s35, s36* are closed and the sectionalizing switches *s32, s11, s7*,are now opened. As a result, the line loss is reduced to 138 kW from the base case of 202.418 kW witnessing a 64.418 kW of real power loss reduction. The worst voltage is found to be 0.9568 per unit at 32nd bus and it also falls within the voltage limits.

In the year 1989Shirmohammadi.D et al., [17]carried out reconfiguration of electric distribution networksand reduced the I2R loss to 141.54 kW. In 2002, J.Z.Zhu [16] proposed Refined Genetic Algorithm and lessened the losses to 139.53 kW. Rayapudi Srinivasa Rao [12] suggested Harmony search Algorithm during 2011 to reduce the losses to 138.06 kW. In this paper, DA algorithm is proposed and the loss reduction is 31.19% where the percentage of loss reduction is more when compared to previous results. This proves the effectiveness of the proposed algorithm. The results of 33 bus Test system and the result comparison of the proposed algorithm with the other optimization techniques have been tabulated in Table 1. The voltage profile of the RDS before and after reconfiguration are shown in Fig 3.

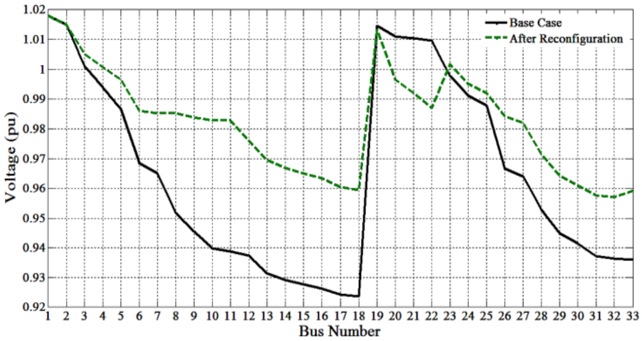

Fig. 3: Voltage Profile of 33 bus RDS

Table 1. Comparative Analysis of 33 bus system

Algorithm	Final Configuration					
	Base Case [12]	RGA [17]	Heuristic [16]	HSA [18]	BFO A [12]	DA
Open Switches	33,34, 35,36, 37	7,10,1 4,32, 37	7,9,14,32, 33	7,914,37, 36	7,10,1 4,37, 36	32,11,7, 34, 37
Power Loss (kw)	202.418	141.5	139.53	139.28	138.0	**138**
Loss Reduction (%)	---	30.08	31.07	31.19	31.79	**31.19**
Minimum Voltage (p.u)	0.9237	0.927	0.9315	0.9210	0.934	**0.9568**

7 CONCLUSION

This paper proposes DA for optimal reconfiguration of Radial Distribution System (RDS) to achieve the best voltage profile and minimal kW losses. A voltage deviation index is established in the paper that finds the deviancy of load bus voltages from the recommended limits. This index is minimized in the proposed algorithm to improve the power quality. The RDS reconfiguration requires the determination of the best combination of feeders in the RDS to be switched out such that the resulting RDS gives the minimum active power losses and the best voltage profile. The DAsolution technique is found predominantly appropriate for solving optimization problems with discontinuous solution space and objectives when the global optimum is desired. The proposed method is tested on established 33-busRDS. The results attained demonstrate that the DA method optimally reconfigures the RDS minimizing the Real power losses and obtains the best voltage profile.

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