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The Reconfiguration Of Radial Distribution Networks With Distributed Generation For Reliability Improvement And Loss Minimization

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Abstract: **The purpose of the paper is to find the best distributed generators (DGs) location for improving reliability and reducing power loss using distribution system reconfiguration. This is implemented in the presence of the tie-switches. It proposes a search-based algorithm for the reconfiguration problem. Individual DG placement is obtained for all system configurations, and analytical hierarchy process tool is used for finding the overall best location. This is carried out for various system loadings. The proposed methodology has been tested on 33-node, 69-node and 12-node test distribution systems. The main is to improve the distribution system and to minimize the loss in the system.**

Keywords: **VSI; DG; RDS; IC; RES;**

INTRODUCTION

Distribution automation allows flexible control of distribution systems to the utilities, which can enhance the efficiency, reliability, and quality of electric service. One important application of distribution automation can be distribution network reconfiguration. DGs especially renewable energy based distribution generation are widely installed in the distribution systems due to various reasons.

Distribution Systems:

Distribution systems are employed with radial structure in order to obtain operational simplicity. By means of an interconnected transmission network, primary distribution substation receives power from generating stations. Radial Distribution System (RDS) network is passive in nature and transfers power to consumers from the substation. Thus, in RDS the power flow is unidirectional. In case of distribution lines, due to high R /X ratio, high voltage drops, large power loss will occur. Everyday distribution networks are experiencing many changes in the load. At most of the nodes, RDS experience a sudden collapse in the voltage during critical load conditions because of low voltage stability index. In this thesis, for RDS a voltage stability index (VSI) is proposed for all the nodes. It is observed that node with minimum VSI value is more sensitive and leads to collapse in voltage. During past years, several techniques were implemented by placing dispersed sources injecting reactive power like capacitor banks in order to obtain improvement in voltage and to reduction in power losses. Even through the implementation of capacitor placing method which is promising in nature, the voltage profile improvement obtained is below desired voltage level (1.0 p.u.). As RDS is passive in nature, it is less reliable.

Many solutions are suggested recently by incorporating electrical sources based on renewable energy technology to overcome the passiveness of RDS and also to improve reliability of the system and voltage profile. These embedded generations in RDS are called as Distributed or Dispersed Generation (DG).

Distributed Generation (DG):

In recent years, alternate solutions to traditional power stations have been given a high priority due to the limited presence of fuel resources and also to meet electric energy demands. Thus, the renewable resources of energy are considered as the alternative solution to existing fuels. When compared with large fossil fuel based power plants, the sizes of renewable energy based generators are small.

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Classically, most distribution systems (DSs) are radial in nature, contain only one power source, and serve residential, commercial and industrial loads. DSs are also operated at the lowest voltage levels in the overall power networks [1]. Power is delivered in bulk to substations. The substation is usually where the transmission and distribution networks meet. The backbone of the distribution networks typically is comprised of 3-phase mains. Laterals are tapped off these mains and are usually single-phase (unless 3-phase service is required by a customer) [1-2]. In addition, the lines used for DSs tend to have a higher resistance to impedance ratio (R/X) than the lines in transmission networks [2]. The modern power distribution network is constantly being faced with a very rapid growing load demand, this increasing load is resulting into increased burden and reduced voltage also effect on the operation, planning, technical and safety issues of distribution networks [9-11]. This power losses

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in distribution networks have become the most concerned issue in power losses analysis in any power networks. In the effort of reducing power losses within distribution networks, reactive power compensation has become increasingly important as it affects the operational, economical and quality of service for electric power networks. The planning should be such that the designed system should economically and reliably take care of spatial and temporal load growth, and service area expansion in the planning horizon.

In [1,2], various distribution networks planning models presented. The proposed models are grouped in a three-level classification structure starting with two broad categories, i.e., planning without and with reliability considerations. Planning of a distribution system relies on upon the load flow study. The load flow will be imperative for the investigation of distribution networks, to research the issues identified with planning, outline and the operation and control. Thusly, the load flow result of distribution networks ought to have ronodet and time proficient qualities. The load flow for distribution system is not alike transmission system due to some in born characteristics of its own. There are few techniques are available in literature. Ghosh and Das proposed a method for the load flow of radial distribution network using the evaluation based on algebraic expression of receiving end voltage. Dharmasa et al. [69] present, non-iterative load flow solution for voltage improvement by Tap changer Transformer in the distribution networks. Teng et al. [70] has proposed the load flow of radial distribution networks employing node-injection to branch-current (BIBC) and branch-current to node-voltage (BCBV) matrices. With the deregulation of energy markets, escalating costs of fossil fuels, and socio environmental pressures, power networks planners are starting to turn away from the centralized power networks topology by installing smaller, renewable-powered generators at the distribution level [3-5] which is known as distributed generation. These DG technologies are classified into two categories: (i) renewable energy sources (RES) and (ii) fossil fuel-based sources. Renewable energy source (RES) based DGs are wind turbines, photovoltaic, biomass, geothermal, small hydro, etc. Fossil fuel based DGs are the internal combustion engines (IC), combustion turbines and fuel cells [3] [6-7]. Distributed generators (DGs) have the advantages of having low environmental emissions, being more flexible in installation and with shorter gestation periods [37]. The technologies behind these renewable-powered generators are evolving to make these generators more utility-friendly (and thus more economical). Some of the DG technologies compete with conventional centralized generation technologies in operational aspects and cost. DG allocation in distribution system is basically a complex combinatorial optimization issue which requires concurrent optimization of multiple objectives [15], for instance minimizations of real and reactive power losses, node voltage deviation, carbon emanation, line loading, and short circuit capacity and maximization of network reliability etc. Presently, a large number of research papers are available on the subject of the DG allocation for power loss, voltage improvement, etc.

ALLOCATION OF DG IN DISTRIBUTION NETWORKS

3.1 Introduction

Loss Minimization in power networks has assumed greater significance, in light of the fact that enormous amount of generated power is continuously squandered as losses. Studies have demonstrated that 70% of the aggregate networks losses are happening in the distribution networks, while transmission lines represent just 30% of the aggregate losses [1]. The pressure of enhancing the overall proficiency of power delivery has forced the power utilities to reduce the loss, particularly at the distribution level. The following approaches are embraced for reduction of distribution networks losses [1-2].

- Reinforcement of the feeders.
- Reactive power compensation.
- High voltage distribution networks.
- Grading of conductor.
- Feeder reconfiguration.
- Distributed Generator placement.

Smart grid concept is expected to become a backbone in Europe future electricity network [10].

In achieving a Smart Grid concept, a large number of distributed generators (DG) are needed inside distribution network which is prognosed to supply up to 40% of the distribution network's load demand. This substantial number of DG is obliged to take part in enhancing the security, reliability and quality of electricity supply by providing active power and other subordinate services such as regulating the voltage by providing their reactive supply to the network. One of the characteristics of future electricity network under smart grid idea is to have an efficient transmission and distribution network that will reduce line losses [3-9]. Minimizing losses inside power transport networks will being about easier utilization of fossil fuel consequently reduced emanation of air pollutant and greenhouse gasses. Coordinating of

DG inside distribution network reduces power losses in light of the fact that some share of the required load current from upstream is generously reduce which result lower losses through line

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resistance. Further reduction of losses can be attained by intelligently managing reactive power from introduced DG [10].

3.2 Distribution Network Power Losses

An active power loss in the line depends on magnitude of the current flows through the line and resistance of the line. In ac distribution circuit, due to electric and magnetic field produce by the flow of time varying current, inductance and capacitance might be noteworthy. At the point when current flow through these two components, reactive power which transmit no energy is produced. Reactive current flow in the line adds to extra power losses in addition to active power losses mention previously. Integration of DG already reduced active power losses because some portion of power from upstream is already reduced. Losses reduction can be further reduced by controlling the voltage profiles in the network. In conventional practice, capacitor banks are added in the distribution network to control the flow of this reactive power.

These capacitor banks can be switched in and out using voltage regulating relay to deliver reactive power in steps but it lowered power quality delivered to the customer as it leads to step changes in node-bar voltage.

$$P_{loss}(x) = \sum_i 3\, I_i^2 R_i \qquad \forall i = N_L$$

3.3 Distributed Generation

3.3.1 Operational and Planning Issues with DGs

Distributed Generators (DG) are crisply characterized as "electric power sources joined specifically to the distribution system or on the client side of the meter" [3]. This definition for the most part obliges a variety of technologies and execution crosswise over diverse utility structures, while evading the pitfalls of utilizing more stringent criteria focused around standards, for example, power ratings and power delivery area. Distribution planning includes the investigation of future power delivery needs and options, with an objective of creating a precise course of action of increases to the networks required to attain agreeable levels of service at a minimum overall cost [4]. Executing DGs in the distribution system has numerous profits, yet in the meantime it confronts numerous restrictions and limitations. DG units, being adaptable, could be built to meet immediate needs and later be scaled upwards in capacity to take care of future demand growth. Versatility permits DG units to reduce their capital and operations costs and therefore substantial capital is not tied up in investments or in their support infrastructure. Investment funds can likewise be accomplished since infrastructure updates, (for example, feeder capacity extensions) might be deferred or altogether eliminated.

PROPOSED METHODOLOGY AND SIMULATION RESULTS

The proposed methodology is tested on 33-node and 69- node and 120 node test distribution systems. The distribution network reconfiguration with distributed generation for the improvement of reliability and minimization of real power losses is proposed. The coding is carried in Matlab 2016a and is used. It is assumed for all the test systems that the system is fully automatized with sectionalizing switches in all the lines. Initially, tie-switches are placed at end nodes considering geographical constraints and then preceded by optimal siting and sizing of DGs at these tie-switch locations. DG placement is carried out at the terminal nodes of the system with alteast one DG at tie-switch as constraint and for sizing *fmincon* solver which is a constrained nonlinear optimization method is used. The data for the tie-switches are considered same as the lines connected adjacent to them.

The objectives is the minimization of real power losses and improvement of voltage profile subjected to the voltage limits, power balance equations and the real and reactive power generation of DG must be greater than losses and less than total system load as given in eqs. (5)-(10). In this project, DG is modeled as a PQ node i.e., negative load.

$$\text{Minimize } \sum_{j=1}^{l} r_j (P_j^2 + Q_j^2)/V_j^2 \quad \textbf{(6)}$$

$$\text{such that } \sum_{i=1}^{n} P_{Gi} \le C \quad \textbf{(7)}$$

$$\sum_{i=1}^{n} Q_{Gi} \le C \quad \textbf{(8)}$$

$$P_i = P_{Gi} - P_{Di} \quad \textbf{(9)}$$

$$Q_i = Q_{Gi} - Q_{Di} \quad \textbf{(10)}$$

$$0.95 \le V_j \le 1.05 \quad \textbf{(11)}$$

r is the resistance of the line j, V is the voltage at the receiving end of the line j, P, Q are total real and reactive power loads fed from receiving node of the line j, C is the total load on the system, Q_{Ci}. The final step is the network reconfiguration considering reliability and power loss. In this step, all the loops formed by closing the tie-switches and the minimal cutsets are found. Constraints for this problem are maintaining system radial nature, power balance equations and voltage limits. All the components are assumed to have identical reliability data with failure rate, repair time,

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maintenance rate and maintenance time as 0.02outages/year, 30hours, 0.2 outages/ year and 20 hours respectively. Distribution load flow algorithm is used for the power loss calculation and reliability evaluation models are used for calculating system reliability, downtime. The proposed methodology is explained using the following example shown in Fig. 4.1

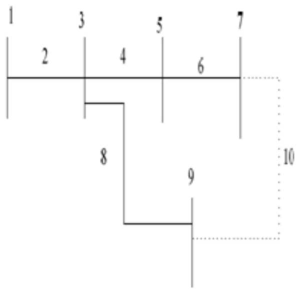

Fig. 4.1 Example distribution system

It is assumed that the test system is fully automated with sectionalizing switches on all the lines. The terminal nodes for the example system are nodes 7 & 9. Tie-switch is placed between the nodes 7 & 9, which will be in open position. Now DG placement is carried out with atleast one DG to be placed as constraint. Node 7 is selected for DG placement. The optimal DG size obtained is $P_{DG} = 103kW$, $Q_{DG} = 75kW$ satisfying all the constraints. Now search based reconfiguration problem will be carried considering both reliability improvement and power loss minimization which is multi-objective in nature. All the components are assumed to have identical reliability data with failure rate, repair time, maintenance rate and maintenance time as 0.02outages/year, 30hours, 0.2 outages/ year and 20 hours respectively. Using probabilistic reliability evaluation method, the unavailability of all the load nodes without tie-switch 7-9 are given in Table 1. Initial step is collecting the required information i.e., reliability data, tie-switches placed. The minimal cutsets are found using dynamic programming with and without considering tie-switches. Table 1 gives the unavailability and minimal cutsets for the system without tie-switches.

Table 1 Unavailability of load nodes

Output node	Load to supply paths	Unavailability
3	3,2,1	0.3120e-3
5	5,4,3,2,1	0.5200e-3
7	7,6,5,4,3,2,1	0.7280e-3
8	9,8,3,2,1	0.5200e-3

Table 2 Loops formed by closing tie-switch

Loops	Lines involved in loop
3-4-5-6-7-10-9-8-3	3-5, 5-7, 3-9, 7-10

The loop formed by closing tie-switch 7-9 is 3-4-5-6-7-10- 9-8 and is given in Table-2. Constraints for this problem are maintaining system radial nature, meeting power balance equations and voltage limits. Average system unavailability is 0.5616e-3.

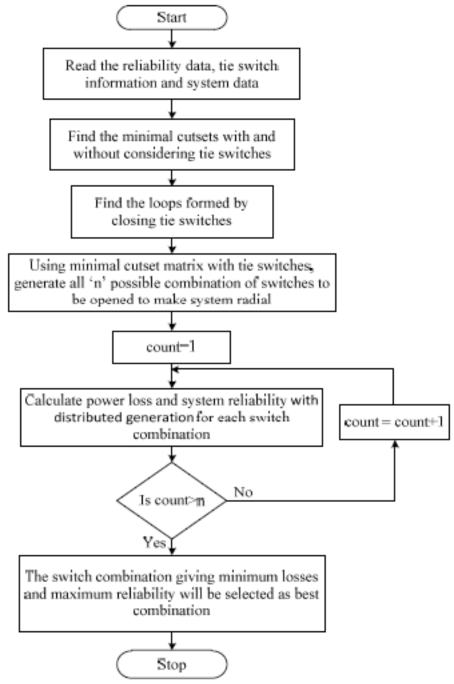

Fig. 4.2 Flow chart for the network reconfiguration

The final step is the network reconfiguration considering reliability and power loss. A search algorithm is formulated for the reconfiguration problem which is explained with the help of a flow chart shown in Fig. 4.2. The reconfiguration algorithm runs as many times as total switch combinations excluding the tie-switches. In each iteration, those lines sectionalizing switch will be opened in such a way that system radial nature is preserved and the power loss and the system reliability is calculated. The switch configuration which is giving minimal losses and high reliability will correspond to the optimal network configuration and the same is explained in the flow chart.

A. 33-node distribution system

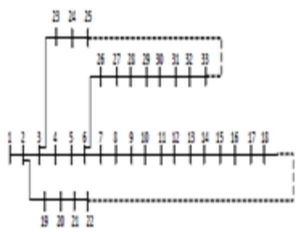

Fig. 4.3 Modified 33 node distribution system

The procedure explained in the previous section is followed for the 33 node test system too. The system is as shown in Fig. 4.3 with tie-switches as dotted lines. Initially, tie-switch placement is carried out taking geographical constraints. The tie-switch locations selected are 18-22 and 25-33 and they will be in open position before

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reconfiguration. Now DGs are placed at these tie-switch node with atleast one DG at a tieswitch. The positions for DGs are obtained as nodes 18 and 33. The DG size problem is done using *fmincon* solver using objective and constraints as given in eqs. (6)-(11). The optimal real and reactive DG size obtained is given in Table 3.

Table 3 Optimal size of DG for 33 node system

	Bus 18	Bus 33
P_{DG}	647	1143
Q_{DG}	400	708

It can be observed that after DG placement, losses got reduced by 76% and with reconfiguration algorithm considering both DG and tie-switches reduced the losses by 78% and reliability also improved. The real and reactive power generation fed from substation after DG placement reduced 49.7% and after network reconfiguration it further got reduced to 33.4%.

Power loss:	208.4592 kW	148.6552 kW
Power loss reduction:	______	33.006 %
Minimum voltage:	0.91075 pu	0.94234 pu
Injected value Kse:	1	
Oupqc(MVAr):	0.8 pu	

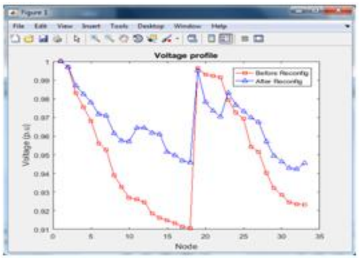

Fig. 4.4 Voltage profile for base and after DG placement for 33 node system

B. 69-node distribution system

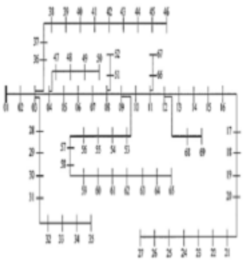

Fig. 4.5 66 node test distribution system

The tie-switch placement is carried out at end nodes. In this test system shown in Fig. 4.5, the end nodes are 27, 35, 46, 50, 52, 65, 67 and 69. The tie-switches are placed at 27-35, 50- 52, 46-67 and 65-69 and these will be in open position. Now DG siting and sizing is carried out in two steps. Initially DG placement at the tie-switch locations is done with constraint as atleast one DG at a tie-switch and is done using simple binary integer programming. The optimal DG locations are 35, 50, 65 and 67. The DG sizing has been carried out using *fmincon* solver with loss minimization as objective and the constraints are meeting load, power balance equations and voltage limits as in eqs. (6)-(11). Table-6 gives the real and reactive optimal DG size for this test system.

	Bus 35	Bus 50	Bus 65	Bus 67
P_{DG}	297	556	1317	888
Q_{DG}	210	394	933	629

Tie switches:	61 62 63 64 65	7 11 32 34 37
Power loss:	208.4592 kW	151.1352 kW
Power loss reduction:	______	31.8163 %
Minimum voltage:	0.91075 pu	0.93996 pu
Injected value Kse:	0.5	

The simulation results for 69 node system is shown below

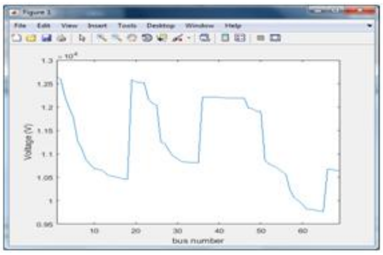

Fig 4.6 Voltage profile of 69 node system before reconfiguration

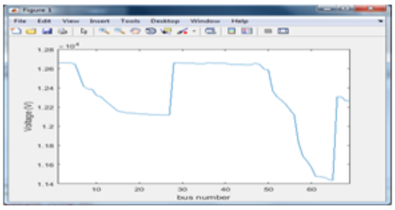

Fig 4.7 Voltage profile 69 Node system after reconfiguration

C. 120 Node distribution system

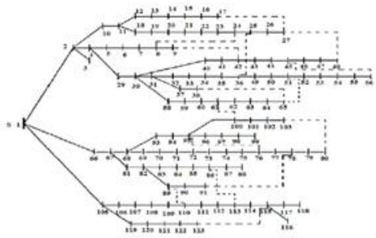

Fig. 4.8 120 node test distribution system

The real and reactive power losses and real and reactive power generation fed from substation for the base case, with optimal DG size and after network reconfiguration with both DG and tie-switches. The system losses reduce by 85% with DG placement and further reduce to 90% with network reconfiguration. The 120 bus structure is shown above. The voltage varies 0.94vto 1.4v for 120bus system.

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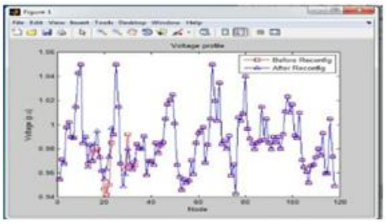

Fig. 4.9 Voltage profile for base and after DG placement for 120 node system

CONCLUSION

The network reconfiguration with optimal DG siting and sizing and tie-switch placement for the reliability improvement and loss minimization is proposed. Tie-switches are placed at terminal nodes with geographical constraints and will be open position. DG siting and sizing is carried out using integer programming with objective minimum DGs and minimization of losses respectively. A search based reconfiguration algorithm has been formulated for finding the optimal switch configuration for the radial distribution system with DG. It can be observed from the results that there is considerable amount of reduction in the losses and improvement in the reliability obtained using the proposed method. The performance of the algorithm is tested on three test distribution systems and the gives better results.

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