Distribution Network with Optimal DG Placement and Protection Impacts: Review Analysis

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Abstract

The rapid increase in the power demand and the capacity shortage of transmission and distribution system drives the integration of Distributed Generation units in Electrical power distribution networks. This integration created a challenge and an opportunity for developing various novel technologies .The aim of the problem is to determine the best location, sizes, type and penetration level of Distribution Generation unit to optimize Electrical distribution network operation considering the various protection impacts and issues. Several methodologies and technologies have been developed to find the solution for this problem. This paper presents an overview of the methodology developed so far to analyze future research trends in this field.

Keywords — *Distributed Generation (DG), Optimal placement models, Real time simulations*

I. INTRODUCTION

Electrical Distribution networks are one of the key elements of Electrical power systems. These systems are characterized by high R/X ratios with either radial or meshed or weakly meshed topology. These networks are close to the consumer side supplying energy from the substation. Though there is need in power generation due to rapid increase in demand, implementation of large conventional power generation plants are not entertained due to environmental and economic aspects. However to meet the demand, generation becomes a mandatory issue. This paved the way for the emerge of renewable energy resources but their capacity being not enough to be compatible with power generation system rather were more suitable for installing in distribution networks near the consumer points. This concept of small Generation Units installed at strategic points of a distribution network or directly to the consumer is coined as Distributed Generation (DG). DG resources are diversified as renewables like solar, wind, fuel cells, and also small capacity of non-renewables such as micro turbines, gas turbines etc. DG penetrations have given both beneficial as well as controversial impacts. It enhances the power quality, efficiency, reliability and operational benefits of a Distribution network by meeting the peak demand, reducing the system losses, regulating the voltage profile. Some of the negative impacts of DG are protection co-ordination, voltage stability and islanding. In order to maximize the benefits and minimize the negative impacts, analyzing the integration of DG into the system is a major concern. Many researchers have formulated various Optimal Placement Models and many other works have also addressed the impacts. This paper presents a review and summary of research developments in integrating DG units optimally in distribution system emphasizing the protection impacts which is an essential part of development of effective smart distribution system.

II. PROBLEM FORMULATION

It is a two stage problem. The first stage being a multi-objective problem in finding an optimum location, size, type of DG in the distribution network under varying penetration levels of DG. This will maximize the benefits such as reduction of the system losses, improvement of the voltage profile satisfying all the constraints. The second stage will be analyzing the protection issues after integrating the DG in the optimal location of the system. The existing protection scheme will also be revised to overcome the issues which rise after the integration.

III. SOLUTION METHODOLOGY

For the first stage of Optimal Placement Analysis, the problem involves the load flow analysis of distribution networks without DG integration, optimize the decision variables of the problem and then perform the analysis with DG to validate the solution. Load flow analysis gives the steady state voltages of electric power systems at fundamental frequency. The load flow problem ensures that voltages and currents are within the predefined ranges for expected loads. Various Optimization algorithms are being implemented to solve for the deciding variables to locate the DG optimally. This step can be broadly analyzed in two approaches: (i) Analytical or Algebraic, which involves the calculation of various parametric indices of the system like loss sensitivity factor, voltage sensitivity index, power loss index etc, based on which the optimum location is determined and using the loss formula the size and type of DG is found. (ii) Heuristic search involves the population based evolutionary optimization algorithms like Genetic Algorithm (GA), Particle Swarm

Optimization (PSO), Artificial Bee Colony algorithm (ABC), Frog Leaping Algorithms which formulates the fitness function and constraints pertained to the problem and solves for the solution variables. For the second stage of Protection Analysis, the optimal distribution network is analyzed to study the issues and impacts of DG on protection schemes and a new protection coordination scheme has to be designed to overcome the issues. The following section briefs both the stages and gives a review of the research work done so far in this area.

A. *Optimal Placement Analysis*

1) *Load Flow Analysis*

Load flow analysis will be efficient if it converges quickly and uses minimum memory. The distribution networks are characterized by high R/X ratio and their topology is either radial or weakly meshed with multiphase balanced or unbalanced operation. When the conventional load flow methods like Gauss Seidal, Newton Raphson and other decoupled methods are applied it will get diverged from the optimal solution. Hence the analysis is different for distribution network. The solution techniques include Forward and Backward sweep method, Compensation method, Implicit Gauss method, Modified Newton method etc. Various methods were researched in the past years for load flow analysis in distribution network. The literature review of all the above mentioned methods is presented in [1].

2) *Optimization Analysis*

a) *Analytical Approach*

A non-iterative analytical method was proposed in [2] which place DG optimally under uniformly distributed condition. A priority list based on loss sensitivity factors was developed in [3] to determine the optimal locations of the DG units. An analytical approach was developed based on algebraic equations for uniformly distributed loads to determine the optimal operation, size and location of the DG in order to achieve required levels of network voltage.[4] A loss sensitivity factor based on the equivalent current injection, is formulated which determines the optimum size and location of DG so as to minimize total power losses [5]. Analytical expression for finding optimal size and power factor of different types of DG units to achieve the highest loss reduction was given in [6]. Three alternative analytical expressions, including two new expressions, to determine the optimum sizes and operating strategy of DG units considering power loss minimization by considering time-varying demand and possible operating conditions of DG units was framed in [7].

b) *Heuristic Approach*

A multi-objective index-based approach in [8] is developed to optimally determine the size and location of multi distributed generation (DG) units in distribution system with non-unity power factor considering different load models based on particle swarm optimization In [9] the paper presents a new optimization approach that employs an Artificial Bee Colony (ABC) algorithm to determine the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss. The proposed work in [10] finds out the optimal value of the DG capacity to be connected to the existing system using Particle Swarm Optimization (PSO) thereby maximizing the power quality using Voltage Profile Improvement Index (VPII) and Line Loss Reduction Index (LLRI). Minimization of power losses and maximization of voltage stability due to finding weakest voltage bus as well as due to weakest link in the system are considered in the fitness function. A new methodology using Real Coded Genetic Algorithm (RCGA) for the placement of Distributed Generating (DG) units in the radial distribution systems to reduce the real power losses and to improve the voltage profile is proposed in [11]. The objective function including the DG units' and capacitors' costs, power losses, and voltage stability margins as a multi objective optimization problem, which uses a developed genetic algorithm as the first stage in the proposed hierarchical optimization strategy with different types of DG units are modeled in[12]. Determination of optimal location and sizing of DG units using multi objective performance index (MOPI) for enhancing the voltage stability of the radial distribution system using weighting coefficients and solved under various operating constraints using a Chaotic Artificial Bee Colony (CABC) algorithm is proposed in[13]. A novel technique combining genetic algorithm (GA)/particle swarm optimization (PSO) is presented for optimal location and sizing of DG on distribution systems to minimize network power losses, better voltage regulation and improve the voltage stability in [14]. Fireworks Algorithm (FWA) is used to simultaneously reconfigure and allocate optimal DG units in a distribution network. FWA is a new swarm intelligence based optimization algorithm which is conceptualized using the fireworks explosion process of searching for a best location of sparks [15]. Multi-objective functions have been formulated with the consideration of minimum investment and operational cost of DG, minimum purchasing electricity cost from main grid and minimum voltage deviation using an improved Non-dominated Sorting Genetic Algorithm II has been proposed. [16]. A Hybrid Modified Shuffled Frog Leaping Algorithm solves the problem of the Multi-objective optimal placement and sizing of DG units in the distribution network in [17].An overview of all the above mentioned methods have been presented in [18].

3) Protection Analysis

There are many challenges and issues in integrating the DG in the distribution network. As protection is one of the major concerns, this paper focuses the protection issues and the research contribution done. During fault current condition, the fault current contribution is from all the DG's as well as from the grid. Hence the flow of current in the network is bidirectional [21]. Thus the issues are due to this bidirectional flow of power in the distribution network with DG. The integration of DG creates the following issues in the area of protection.

- Change in fault current level of the network
- Blinding of protection
- Sympathetic tripping or false tripping
- Fuse-Recloser coordination issues
- Unsynchronized Reclosing during islanding

a) Change in Fault Level

The presence of DG in a network affects the short circuit levels of the network. It creates an increase in the fault currents when compared to normal conditions at which no DG is installed in the network. The influence of DG to faults depends on some factors such as the generating size of the DG, the distance of the DG from the fault location and the type of DG. This could affect the reliability and safety of the distribution system. The nature of the DG also affects the short circuit levels. Conventional methods of fault analysis will not be able to identify the MVA capacity of the network with DG. New methods are to be analyzed to determine the short circuit capacity.

b) Blinding of Protection

During fault condition the contribution of fault current will be both from grid as well as the DG. So the grid contribution to the fault reduces and this will lead to undetected short circuit current. The existing feeder relays are designed for the fault current from grid alone. Now with DG as the contribution level decreases this short circuit current never reaches the pickup current of the relay. (Fig.1) This leads to malfunction of the relays and the sensitivity of the protective system is affected. [22]

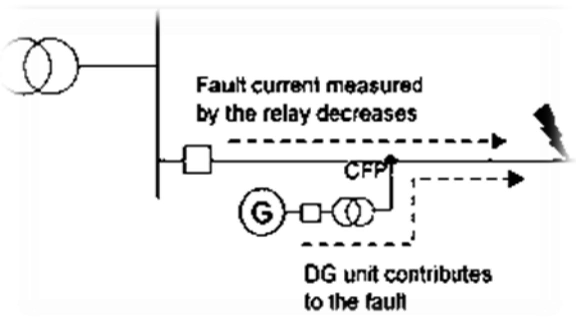

Fig.1. Blinding of protection

c) Sympathetic Tripping

When DG installed on a feeder contributes to fault current in an adjacent feeder the contribution of DG to fault current increases the current in healthy feeder. The maximum current for an upstream fault for which protection should not intervene is higher than the minimum current for a downstream fault for which the protection should intervene [22]. This exceed the pickup level of over current protection which leads to trip of healthy feeder.(Fig.2)

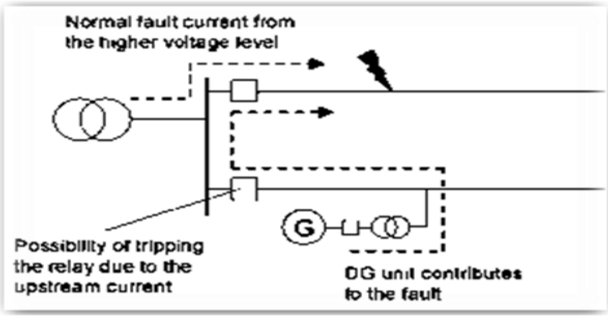

Fig.2. Unnecessary relay tripping

d) Fuse-Recloser Coordination issues

When fast recloser for fuse saving is used in the feeder the coordination between the fuse and recloser is endangered in the presence of DG along the feeder. The generator contributes to the fault current through the fuse but not to the fault current through the recloser. This design is based on the assumption that both will carry the same fault current. The consequence could be fuse operates faster than the reclose is able to open. This causes a long interruption for the customers on the lateral protected by the fuse.

e) Unsynchronized Reclosing during islanding

When there is fault in the feeder there could be opening of the upstream fuse or breaker creating a feeder island supplying the utility load still. When recloser operates during its dead time part of the feeder is disconnected such that it allows the arc to deionize. If DG is present, it keeps the feeder partly energized and maintains the arc at the fault. When the feeder detects the fault and opens the breaker for reclosing, the DG unit still maintains the voltage in the network. (Fig.3). So a temporary fault turns out to be a permanent fault. [22]

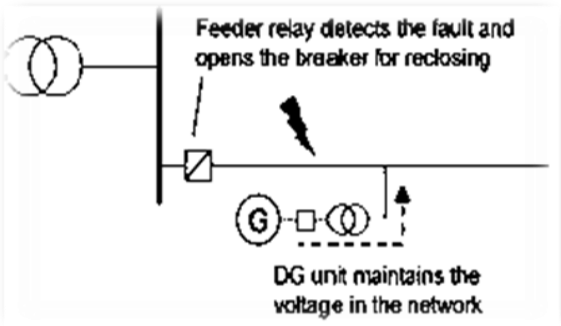

Fig.3. Failing recloser

The available schemes for protective strategies in distribution networks with DG [24], [32-39]

- Voltage based protection
- Overcurrent protection and symmetrical components
- Use of external devices-Fault current limiters, Energy storage devices
- Inverse Admittance relay scheme
- Adaptive protection scheme
- Island detection methods

All the above mentioned methods has its own merits and demerits but more dependent on the network configuration.

The factors to be considered while designing a new protection strategy with DG

- Sensitivity- proper coordination of all protective devices
- Selectivity-minimum system disconnection under fault
- Reliability-correct operation of all devices
- Speed-minimum fault duration
- Simplicity-minimum protective equipment
- Economics-maximum protection with minimum cost

IV. FUTURE SCOPE

Based on the literature survey and analysis some recommendations and scope are given.

- More emphasis is given to optimal placement of DG in network but protection analysis for the optimal network has also to be fully implemented.
- Majority of the proposed protection strategy depends on the configuration of network. Strategies which can address any configuration should be developed.
- Setting schemes to distinguish fault currents and load variations to be implemented.
- An adaptive reliable protection strategy which can discriminate high impedance fault should be proposed with sensitivity and selectivity of all the relays and other protective devices well-coordinated.
- For an optimal protective network the combined action of all the strategies has to be taken into account.

V. CONCLUSION

This comprehensive review study analyzes the optimal analysis of placing DG in a distribution network and further investigates the protection analysis in the optimal network. It gives an insight to the research work done so far and aids for further scope of analysis that could be made further to improve the efficiency of the network.

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