# Abstract

Due to the ever increasing exponential rise in power demand, power utilities around the world are experiencing huge challenges with each and every passing day making the power distribution network more complex and vulnerable to a variety of challenges and issues. These challenges necessitate new ideas and technology to address the issues and prompted for some viable solutions to address the same. Over the last few years, penetration of distributed generation (DG) in power systems has been gradually increasing. The, ever-increasing demand of electric power without sufficient transmission and generation enhancement adversely affects the reliability, security and power quality of a power system, and also causes excessive power loss in the network. Introduction of DG in distribution system can result in a number of benefits which can provide solutions to the various problems the traditional power systems are facing now-a-days.

The DGs that are inserted to reap the benefits are found to have addressed most of the issues. However, they also suffer from some major technical flaws, which are primarily attributable to the interfacing of converters at various stages. The two most prominent and sought after benefits of efficient DG planning are reduced active power loss and improved voltage profile. Because of the significant overall losses that a distribution system network experiences as a result of its design considerations, extensive research and analysis has been conducted in order to determine the best conditions for reducing network losses and improving voltage profile .

Lately, the DG units are based on various renewable energy resources as renewable based generation are environment friendly and do not emit pollutant gases. Majority of the renewable based DG units are connected to the power network through power electronic inverters which are leading to introduction to harmonics. The problem of harmonic contamination and the resulting low power profile, however, has long been overlooked.

Despite the fact that power systems are designed to run at frequencies of 50 Hz or 60 Hz worldwide, certain types of loads (non- linear loads) produce currents and voltages at integral multiples of the fundamental frequency,  resulting in harmonics in the networks. Among these

non linear loads, a different type of power electronic loads such as adjustable speed drives (ASD), Switching Mode Power Supply (SMPS) and various other devices using power electronic converters are the most significant components injecting harmonic currents in the network and thereby producing harmonic distortions. The problem of harmonic distortion is more prominent in distribution networks. With the increasing use of Power Electronics loads in recent times, the problems associated with harmonic distortions have reached alarming stage, and therefore requires special attention in the problem of design, planning and operation of power networks, particularly the distribution networks.

Presence of harmonics in the network causes several detrimental effects on power system operation such as deterioration of power factor, higher system losses, overheating of the network components, degraded voltage profile, and malfunctioning of the protection and control devices. Consideration of these factors in planning, design and operation is extremely crucial. The problem is more aggravated by the fact that the degree of distortion and the distribution of its effect along the network is quite complex and dynamic in nature in the sense that it is dependent of the harmonic nature of the non linear elements and their locations in the network.

In this context it is very important to note that majority of the DGs is now- a- days renewable based and are connected to the network through power electronic inverters which injects harmonics into the network. Installation of such DG units affects the harmonic distortion profile in the network and the ultimate profile depends on the size (capacity) and location of the DG unit. Giving due importance to the requirement that the maximum harmonic distortion level should be kept within some limit for healthy and reliable operation of the devices in the network, the size and location of the incoming DG unit must be selected with due consideration to this crucial requirement.

## MOTIVATION BEHIND THE STUDIES UNDERTAKEN

It has already been mentioned in section that introduction of DG in distribution network can provide a number of benefits. However, to get those benefits to the fullest extent, proper DG planning related to appropriate location and size is essential. Studies are therefore required for determination of proper location and proper size of DG unit to be installed in order to achieve specific benefits. One of the major benefits gained from DG placement is reduction in network power loss and has been addressed by many researchers without considering the presence of harmonics. However, as discussed in section 1.3, the distribution networks now-a- days are affected with appreciable amount of harmonic distortion because of high degree of penetration of power electronic loads. Moreover, majority of the DG units presently are renewable based and use power electronic inverters. In such a situation, it is essential to include the effects of these harmonics sources in the study of optimal DG placement.

The aim of the studies undertaken here is to explore the problem of optimal placement of DG unit for loss minimization in radial distribution network polluted with harmonics. Relatively few researchers have considered the presence of harmonics in the study of optimal DG placement. However, all these studies have employed one or other evolutionary population based method. These evolutionary computing methods are versatile optimization methods as they are capable of solving multi-objective problems and can take into account any number of constraints. But all these methods are highly computation intensive and require large amount of computation for solving DG placement problem. In this context, computationally efficient methods are always desirable so that desired solutions can be obtained with less computational effort.

## SCOPE OF WORK UNDERTAKEN IN THIS THESIS

The studies undertaken in this thesis have focused on the development of computationally efficient methods for solving the problem optimal placement of DG units in radial distribution network to minimize the network power loss when harmonics generating sources are present in the network. In the context of the studies done in this thesis it is to be mentioned that harmonic load flow (HLF) is an important and essential component of the computations required in the optimization process involved in optimal DG placement problem, and has been applied in all the studies reported so far. HLF constitute the major part of computation in this problem. The methods requiring lesser number of HLF to be executed for finding the optimal solution, will, in general, be computationally more efficient than the other methods with respect to the amount of computation needed. In the studies undertaken here, backward-forward sweep method of HLF has been used. The proposed methods have been tested on two benchmark distribution test networks, IEEE 33 bus network and IEEE 69 bus network. In all the studies in this thesis, only inverter based DG units has been considered. Non-linear loads are considered in the studies in chapter 4 to chapter 6 only.

In chapter 2, a Particle Swarm Optimization (PSO) based solution to the DG placement problem has been considered where constraints on bus voltage magnitudes as well as the maximum allowable *THD* in bus voltages have been considered. And the results obtained in this chapter have been used as the benchmark for validation of the results obtained in the later chapters. Results for both unconstrained and constrained cases have been furnished for the two test networks considered in the thesis.

In chapter 3 a novel, computationally efficient iterative process has been developed. The method utilizes the unimodal nature of variation of network power loss with DG size installed at any bus. The method proposed is, however, capable of finding the unconstrained optimal size with fairly small amount of computation.

Chapter 4 has presented a novel hybrid approach to determine the optimal DG size with constraint imposed on maximum allowable value of *THD* in the bus voltages. The hybrid approach is a combination of a Rule-base and some iterative computations among which the iterative method proposed in chapter 3 is also included. The Rule-base is developed based on the nature of variation of power loss and the variation of maximum *THD* with the size of the DG placed at any given bus. The results on the two test networks have shown the computational superiority of this method over the PSO based method.

In chapter 5 a novel analytical method is presented, which is capable of finding the unconstrained optimal size with very little amount of computation using *B*-coefficient loss formula for expressing the network power loss as a function of the DG size with some approximation. Comparative studies with the results of chapter 2 and chapter 3 have shown the superiority of this method in terms of amount of computation required.

In chapter 6, some iterative steps are introduced to improve the results from the analytical method at the cost of small amount of increase in computation. The results have shown marked improvement where the difference between the analytically obtained size and the exact optimal size is quite larger. In cases when improvement was possible, only two iterations were sufficient to get the maximum possible improvement.

In a nutshell the studies undertaken in this thesis have focused on optimal placement of DG units in radial distribution network to minimize the network power loss when harmonics generating sources are present in the network. The main objective of these studies was to develop computationally efficient method for solving such problems as in recent years increased use of power electronic loads (non linear loads) has increasingly given rise to harmonics pollution in the distribution networks. Moreover, one of the adverse effects of application of DGs is that it increases the problem of harmonic contamination. The problem remains more pronounced as renewable based DG units are interfaced with the network through power electronic inverters which are major sources of harmonics injecting harmonic currents into the network. In the work undertaken four computationally efficient methods have been proposed which were tested on two benchmark radial distribution networks such as IEEE-33 and IEEE-69 bus network. The results obtained have shown the superiority of the methods suggested over other meta-heuristic techniques in DG placement planning for a harmonics contaminated network for both constrained and unconstrained situations.