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Implementation of Distributed Generation (IDG) algorithm for performance enhancement of distribution feeder under extreme load growth

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ABSTRACT

This paper presents a new algorithm, written in C-language for Implementation of Distributed Generation (IDG) to radial distribution feeder, heavily overloaded with non-uniformly distributed load. Majority of the existing algorithms are designed for distribution feeders with uniformly distributed load, working in single DG scenario. The applicability of these algorithms is restricted because of the unity power factor and high computational work. The methodology proposed in the research paper is capable of functioning under randomly distributed load conditions with low power factor for single DG as well as multi-DG system. The algorithm is based on analytical approach and is implemented to radial distribution network, considering the worse case scenario. The analyses carried out show that the algorithm can be applied to enhance the performance of distribution system in terms of node voltage profile improvement and power loss reduction. The simulation results indicate that IDG is capable of identifying the optimal location and size of DG in any problematic distribution system effectively. The results obtained are verified and are within the international standards limits.

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1. Introduction

Before the advent of Distributed Generation (DG), mostly the distribution networks were designed to operate without any distributed resources along the feeder. The deregulation of electric power market and the global concerns about the environment have diverted the attention of distribution planners towards DG. The penetration of DG in the distribution system changes the power flow configuration in the traditional network of electric power distribution system from unidirectional to multidirectional system. The introduction of DG in the distribution system changes the operating features and has significant technical and economic impacts. One of the main obstacles for high DG penetration in the distribution feeder is the voltage rise effect which can be rectified by the selection of appropriate size and number of DGs [1]. The decreasing availability of natural resources and the increasing consciousness of environmental protection have rapidly increased the share of DG in the electricity supply. This share may increase to 20% in the European countries by the 2020 [2]. Distribution system performance can be improved with the effective integration of DG. Under such circumstances, the DG offers a feasible alternative to traditional sources of the electric power. The installation of small generating unit affects the operation of electric utility system in term of its performance improvement and reliability. The utilization of DG with optimal rating provides substantial relief to distribution network during the peak hour's demand [3]. Keeping this in view, the classical modeling and analyzing techniques must be revised. In past various optimization techniques for the voltage profile improvement, loss reduction, and optimal placement of DG in the electric distribution system have been proposed [4–7,8]. The mathematical analysis includes Gradient techniques, Successive Quadratic Programming (SQP) techniques, Karush Kuhn-Tucker non-linear programming techniques, and successive linear programming (SLP) techniques. Miu and Chiang have given a formulation for a large scale distribution network. They have analyzed a distribution network with the uniform and non-uniform load variations [7]. Wang and Nehrir have presented an analytical approach which is applicable only for the uniformly distributed load with unity power factor [8].

Majority of these techniques have the problem of excessive convergence time and premature convergence. Practically, it has been observed that majority of the distribution feeders are lengthy, heavily overloaded, having limited provision for future expansion and feeding non-uniform loads with non-unity power factor. In such scenario, the electric consumers are facing many problems because of the excessive voltage drop and power loss [9]. Poor equipment performance, overheating, nuisance tripping of over current protective devices and excessive burnouts are the sign of an unsatisfactory voltage profile. Unlimited voltage variation directly deteriorates the equipment life. Many industrial

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Nomenclature

ΔP_{loss}	incremental power loss
P_{loss}	power loss
dE_x	incremental voltage drop
E_{drop}	voltage drop
E_s	voltage at sending end of the feeder
E_x	voltage at distance "x" from sending end
E_r	voltage at receiving end of the feeder
ΔP_{lossDG}	incremental power loss with DG
P_{lossDG}	power loss with DG
dE_{xDG}	incremental voltage drop with DG
E_{dropDG}	voltage drop with DG
$\frac{dI}{dt}$	change in segment current without DG
$\frac{dI_{DG}}{dt}$	change in segment current with DG
θ_n	phase angle between voltage and current of nth segment
EP	voltage profile at different nodes without DG
EP_{DG}	voltage profile at different nodes with DG
EP_1	voltage profile index
$EPII_1$	voltage profile Improvement index
EP_2	modified voltage profile index
$EPII_2$	modified voltage profile improvement index
E_{nom}	nominal value of voltage in per unit
$E_{\max}$	maximum value of voltage in per unit
$E_{\min}$	minimum value of voltage in per unit
E_i	any value of voltage in per unit at node "i"
L_i	load supplied at ith node in per unit
K_i	weighting factor of different loads connected
$N = 0, 1, 2, \ldots$	number of nodes
I_N	load connected to "N" node in ampere
$Z_{0,1}, Z_{1,2}, \ldots Z_{n,n+1}$	impedance of nth segment of feeder in Ω per unit length
$R_{0,1}, R_{1,2}, \ldots R_{n,n+1}$	resistance of nth segment of feeder in Ω per unit length
$L_{0,1}, L_{1,2}, \ldots L_{n,n+1}$	inductance of nth segment of feeder in H per unit length
$x_{0,1}, x_{0,1}, x_{0,1}$	length of nth segment in meter
$I_{0,1}, I_{1,2}, \ldots I_{n,n+1}$	current flowing in nth segments of feeder in ampere
$n = 0, 1, 2, \ldots$	any number

consumers have experienced substantial financial losses resulting, obstacles in the good quality of the electricity supply. Non-uniform distribution of electric loads on the distribution feeder, the use of under sized conductors, remote location of transformers from the load centers, sub-standard jointing practices, and the long length of the distribution feeder are the major causes of the voltage drop and power loss. Continuously increasing demand of the electricity and proliferation of different non-linear loads such as rectifiers, switch mode power supplies, arc furnaces and other switching converters have also contaminated the quality of voltage for consumers having sensitive equipments. Lack of financial resources, unavailability of sophisticated technology and the non-implementation of long term planning has further deteriorated the quality of electric supply and complicated the distribution system. Haphazard distribution of electric loads over the feeder in general and mixed nature of loads in particular on the feeder causes sever problems of power quality i.e. the voltage drop and power loss. Such problems are detrimental to the consumers as well as to the electric utilities.

Under such circumstances, IDG tool has been design, which could be used to simulate and analyzed the feeder having non-uniform distribution of electric load. The analytical approach is adopted to enhance the power quality of distribution feeder in terms of the node voltage profile improvement and power loss reduction. It is too difficult to improve the performance of distribution system without optimal size and location of DG. In this context, IDG tool has been developed to identify the optimal size and placement of DG in the distribution system. Taking the real worse case scenario, the algorithm has been implemented on the 11 kV Panian radial distribution feeder with non-uniformly distributed loads. The feeder has 168 numbers of nodes and is almost about 100 km long, emanating from 132 kV Haripur grid station, Peshawar electricity supply corporation Pakistan. It has 132 numbers of transformers with total load of 8425 kVA.

The proposed method can be utilized effectively to increase the feeder performance, having non-uniformly distributed loads. Elaborative results are presented to assess the performance of distribution feeders as potential custom power solution. The feeder has been simulated in C-language and the results are verified analytically, which are within the acceptable limit of international standard. For convenience, the radial distribution feeder is divided into segments between the nodes. Non-uniform loads are connected to each node. The length and impedance for each segment are calculated. Mostly, the distribution feeders are lengthy and heavily overloaded in under-developed countries. Keeping in view of the complex nature of the feeders, it is essential to generalize these feeders so that one should be able to analyze them successfully. The same objective has been achieved by reducing the single line diagram of the feeder from 168 nodes to 38 nodes by adding the loads of laterals and sub laterals to subsequent nodes as shown in Fig. 5. However, practically it has been observed that it does not affect the analysis of the feeder.

Majority of the optimization techniques are complex, rigor and involved more mathematical computational work. Heuristic techniques provide empirical results and no performance guarantee; linear programming does not directly yield an improved estimate of the optimum and in successive linear programming, algorithm generates a sequence of infeasible points which can not be terminated early with optimal solution [10]. These techniques are useful only for on-line performance improvement calculation. Whereas, the implementation of IDG algorithm is easy, simple and no on-line calculations are required. The algorithm can be implemented easily with the personnel computer in off-line condition and no heavy computational work is required. The analyses show that optimum results for any problematic feeder can be achieved within the fraction of millisecond. The basic data for comprehensive algorithm is obtained from the single line diagram, generated during the field survey as depicted in Fig. 4. This data is stored as a "Data File", contains length ($X_{0-1}, X_{1-2}, \ldots, X_{n-n+1}$) of each feeder segment and load in amperes ($I_1, I_2, \ldots, I_n$) connected to each node. These known values are further used to calculate the total load (S_i), segment currents ($I_{0-1}, I_{1-2}, \ldots, I_{n+1}$) segment voltage drops ($V_{0-1}, V_{1-2}, \ldots, V_{n-n+1}$), node voltages ($V_1, V_2, \ldots, V_{n-1}, V_n$) and load currents ($I_1, I_2, \ldots, I_{n-1}, I_n$) as follows:

- $S_i = S_1 + S_2, \ldots, S_n$, where $S_1, S_2, \ldots, S_n$ are the known values of load connected to individual nodes and stored in the "Data File", where $i = 1, 2, \ldots n$.
- The voltage at the reference node (V_0) is known.
- $I_{Total} = I_{0-1} = \frac{S_i}{\sqrt{3}\text{kV}_0} = \frac{\text{KVA}_{Total}}{\sqrt{3}\text{kV}_0}$, where I_{Total} = total current supplied by the source at reference node.

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