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Multi Objective Evolutionary Programming Based Optimal Placement of Distributed Generators



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Abstract:

In this paper, an evolutionary programming (EP) based technique has been presented for the optimal placement of distributed generation (DG) units energized by renewable energy resources (wind and solar) in a radial distribution system. The optimal location of DG is determined by using the loss sensitivity factor and voltage stability index. The correlation between load and renewable resources has been nullified by dividing the study amount into many phases and treating every segment severally. The solutions lead to significant loss reduction and voltage profile improvement. To reduce the search space and thereby to minimize the computational burden, a sensitivity analysis technique has been employed which gives a set of locations suitable for DG placement. For the proposed EP based approach, an index based scheme has also been developed to generate the population ensuring the feasibility of each individual and thus considerably reducing the computational time. The proposed optimization technique is tested on standard 69-bus test system and the obtained results are compared with the exhaustive load flows.

Index Terms:

Distributed generation, evolutionary programming, renewable energy resources, sensitivity analysis.

I. INTRODUCTION:

Recently there is a lot of demand in the integration of distributed generation (DG) units at the distribution level. DG could effectively improve the power system stability, power quality and energy efficiency. The advantages of DG depend on how these devices are placed in the distribution system based on the best location and optimal size.

DG is a small scale electricity production which is generally connected in the distribution system. The capacity of DG plants ranging in from l0kW to 15MW. DG units are closer to consumers, Therefore Transmission and Distribution (T&D) costs are reduced. It is easy to find sites for small generators. Usually DG plants require shorter installation times and the investment risk is not too high. DG plants have good efficiencies DG effects different parameters of a power system, consists of voltage profile, line losses, short circuit current, amount of injected harmonic, and system reliability and stability. In order to install DG units these parameters have to be appropriately investigated. By using an optimization technique which is capable of indicating the best solution for a given distribution network. Distribution generation has many types which includes wind turbines, photovoltaic cells, fuel cells, battery energy, storage systems, micro turbines, internal combustion engine, cogeneration system, fuel-cells, biomass, and micro turbines, small Hydro electric plant, etc.

The integration of distributed generation (DG) with distribution system offers several technical and economical benefits to utilities as well as to customers. However, mere inclusion of DGs may not guarantee the improvement in system performance. Depending on the size, location and penetration level, DG may have negative impacts on the performance of distribution network. Hence, a proper allocation of DG units in the distribution system plays a crucial role. For DG placement in the distribution systems, various issues, such as reduction of system power loss, improvement in system voltage profile, diminution of harmonic pollution, maximization of DG capacity, minimization of investment etc., have been aimed at by researchers in their single or multi-objective problem formulations. Different optimization techniques, such as Primal-Dual Interior-Point method, mixed integer nonlinear programming, evolutionary programming (EP) technique, analytical approach, trade-off method,

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Hereford Ranch algorithm, linear programming technique, genetic algorithm (GA) technique, heuristic approaches, Classical Second Order method, Tab Search approach, and Decision Theory approach have been exploited to solve the optimization problems for DG placement. Most of the abovementioned DG placement methods are well suited to allocate conventional resources based DGs like internal- combustion engines, reciprocating engines, gas turbines etc. which are dispatch able and controllable. These methods may not be suitable to place DG units energized by renewable energy resources as these do not incorporate the uncertainties associated with intermittent outputs from renewable energy resources based DGs. This paper attempts to overcome aforesaid issues and presents an EP based approach for the optimal placement of photovoltaic arrays (PVAs) and WTGs in a radial distribution system. Suitable probabilistic models have been employed to represent the uncertainties associated with load and renewable resources. To restrict the wind power dispatch to a certain fraction of system load, two operation strategies have also been adopted and simulated. The developed formulation has been tested on a 69-bus distribution system with encouraging results. This paper begins with the mathematical modeling and formulation of DG placement problem. Then, an EP based algorithm is presented for solving the formulated optimization problem. Finally, the results with test system are presented and relevant conclusions are drawn.

II. MATHEMATICAL MODELING:

Following assumptions have been made to develop the mathematical model for optimal placement of PVAs and WTGs in a distribution system:

1) Since the determination of optimal numbers and capacities of PVAs and WTGs to be placed is a problem of long-term expansion planning, their numbers and sizes are known a priori. In general, the number and size of renewable energy resources based DGs are governed mainly by economic consideration in addition to the renewable resource at the site, electric utility rates, requirements for interconnections, legal and environmental issues, etc.

2) Depending on the control status, the DG buses can be modeled either as voltage-controlled buses or as constant active- and reactive-power buses. In this work, both PVAs and WTGs are assumed to be operated at constant power factors, hence, DG buses are treated as the constant active- and reactive-power buses.

3) The distribution system under consideration is balanced.

$$\text{Sensitivity of } P_L = \frac{\partial P_L}{\partial S} = \frac{P_L^{S+\Delta S} - P_L^S}{\Delta S}$$

The optimal placement of DGs in the distribution systems is a combinatorial optimization problem. Search for the best combination amongst the various possible combinations for DG allocation is computationally arduous even for a small distribution system. The search space, however, can be compacted by reducing the number of candidate locations for DG placement using a suitable sensitivity analysis technique. Hence, to identify suitable candidate/sensitive locations for DG integration, the proposed method starts with calculation of sensitivity of active power loss with respect to active- and reactive-power injections in the distribution system. After calculating the sensitivity of active power loss with respect to active- and reactive-power, the buses are arranged in the descending order of sensitivity values obtained and a desirable number of most sensitive buses are selected as the possible candidates for DG placement.

$$P\left(l_r^t\right) = \frac{\text{Number of occurences of load level } l_r^t}{\text{Total number of load points during } t\text{th time frame}}.$$

The load and renewable resources, mainly solar radiation, are strongly correlated. To nullify the effect of correlation and to be able to treat those independently, the study period is divided into several segments (say segments), each referred to as time frame. For each time frame, solar irradiance is considered as a random variable and is assumed to follow a Beta distribution. Fluctuations in the wind speed and thereby active power generation from WTGs causes imbalance between the generation and demand. This imbalance may lead to the frequency and voltage variation and subsequently, may affect the safety and stability of the system.

Therefore, to avoid such serious problems, the dispatched wind energy is limited to a specific percentage of system demand. The ratio of dispatched wind power to total system load is known as wind power dispatch to load ratio (WPDLR).The WTs can broadly be classified into two categories, namely, pitch regulated WTs and stall regulated WTs. In case of pitch regulated WTs, their blades are physically rotated about their longitudinal axis to control the rotor torque and power from the wind side, while in case of stall regulated WTs, their blade angle is fixed but the aerodynamic performance is designed in such a way that they stall at high wind speeds.

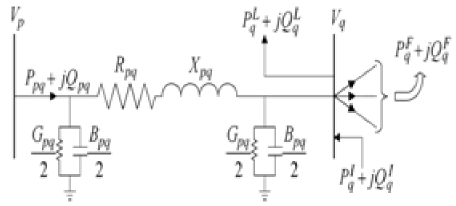

Fig.1. Model of a branch connected between buses

In the presented work, the following two control/operation strategies are adopted to simulate the realistic situation to keep WPDLR within a specified value:

a) Turning off WTG and
b) Clipping WTG output.

In "Turning off WTG" control strategy, WTGs are turned off one at a time until WPDLR is within the prescribed limit. This practice is adopted in the fixed pitch WTGs (stall regulated). In "Clipping WTG output" control strategy, the output from all the WTGs is proportionally reduced until WPDLR is maintained within the prescribed limit. This control scheme is possible in the variable pitch WTGs (pitch regulated).

$$AE^{E}_{Loss} = \sum_{t=1}^{NT} P^{t}_{Loss} \cdot H^{t}$$

In this work, parameter represents the applied control strategy for the WTG type at the candidate location as shown in at the bottom of the page. In this step, first the load flow solution is obtained for each time frame taking into account the previously developed models for the net power injections at candidate locations and for load; and then the solutions are used to analyze the system over the study period. For a branch, as shown in Fig. 1, relations for active power flow, reactive power flow and bus voltages.

III. SOLUTION TECHNIQUE:

The developed formulation for optimal placement of DGs in the distribution system is a combinatorial optimization problem with non-monotonic solution surfaces where many local minima may exist. Classical optimization techniques are not well suited to solve this type of problems.

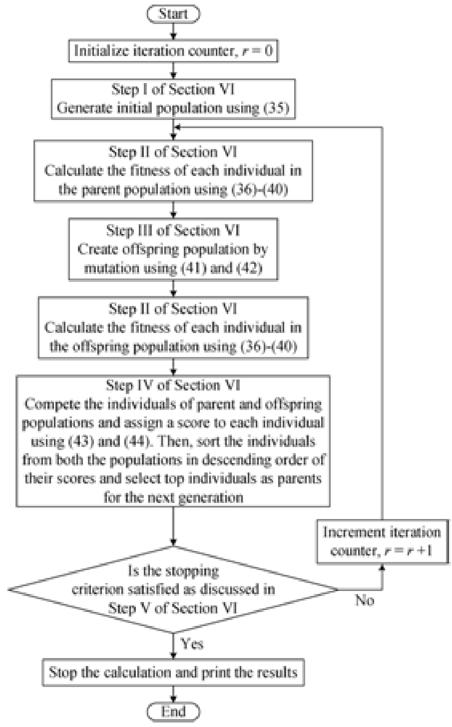

Fig.2. Flowchart for the proposed EP based technique.

The main stages of the proposed EP based technique including initialization, mutation and competition are illustrated with the help of a flowchart in Fig. 2.Hence, an EP based algorithm is used for the solution because these algorithms are emerging as efficient approaches for various search, classification and optimization problems for efficiently finding global optima at a rapid and robust convergence rate regardless of nature/complexity of the problem.

The EP based techniques are well suited for non-monotonic solution surfaces as well as for large-scale real-valued combinational optimization. EP is an artificial intelligence and stochastic method for optimization similar to evolutionary strategy and GA. EP uses the mechanics of evolution to produce optimal solutions for a given problem. It works by evolving a population of candidate solutions toward the global minimum through the use of a mutation operator and selection scheme.

The EP based algorithm is initiated by generating a population of individuals. An individual in the initial population represents a feasible solution. Each variable of an individual is selected randomly using a uniform random distribution over its lower and upper limits.

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IV. RESULTS AND DISCUSSION:

The developed algorithm is applied on a 12.66-kV, 69-bus distribution test system to find out the optimal positions of DG units. The test system is assumed to be situated near Kandla Port (State: Gujrat, Country: India) and data for solar irradiance, ambient temperature and wind speed for this site are obtained respectively. The data for distribution test system are obtained. This system has a peak load of 1.1079 MW. The study period of one year is divided into 12 months and each month is further subdivided into 24 segments, each referring to a particular hourly interval (for example: 08:00–09:00 hours) of the entire month. Thus, there are total 288 (12 24) segments over a year and the number of hours associated with each segment is numerically equal to the number of days in the month under consideration. The historical data of solar irradiance, wind speed and load are also divided into 288 segments and for each segment, appropriate PDFs are developed using the respective historical data. In order to select the buses suitable for DG placement, sensitivity analysis is performed for the chosen distribution system using the approach as described. The active power loss sensitivities with respect to active- and reactive-power injections at different buses of test system are shown in Fig. 4. Bus numbers 54, 53, 52, 51, 50, 49, 48, 47, 46, 27, 26, 25, 24, 23, 22, 21, 20, 19, 18, 17, 16, 15, 14, 45, 13, 58, 57, 12, 44, 56, 55, 11, 43, 10, 42, 9, 41, 40, 8, 7, 6, 39, 38, 35, 34, 5, 33, 37, 69, 68, 67, 66, 65, 32, 64, 31, 30, 63, 62, 61, 60, 36, 4, 29, 59, 28, 3 and 2 have descending order of active power loss sensitivities with respect to both active- and reactive-power injections. Top 25 buses are selected as the candidate buses for placement of PVAs and WTGs in the following two configurations:

1) 1 PVA and 1 WTG, each of 0.25 MW size;
2) 2 PVAs and 2 WTGs, each of 0.125 MW size.

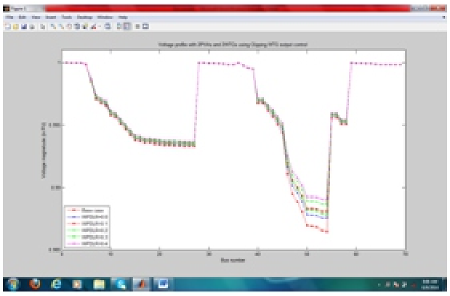

Fig.3 Active power loss sensitivities with respect to (Wrt) active and reactive power injections at different buses in 69-bus distribution system.

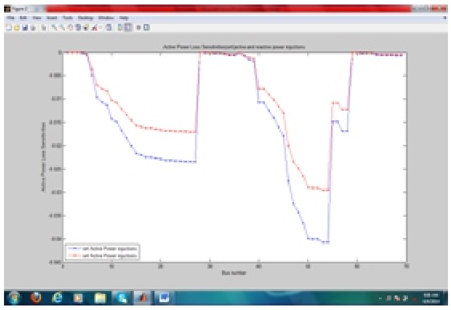

Fig.4 Voltage profile for 69-bs distribution system with 2PVAs and 2WTGs using "Clipping WTG output" control strategy

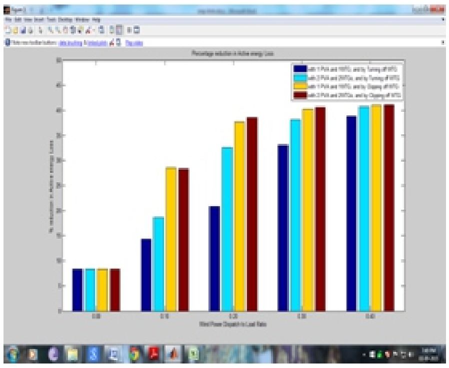

Fig.5 Minimum voltages for 69-bug distribution system for different DG placement schemes

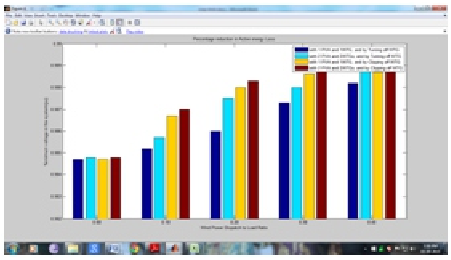

Fig.6 Percentage reduction in active energy losses for 69-bus distribution system for different DG placement schemes.

V. CONCLUSION:

In this paper, an EP based approach has been developed and presented for finding the optimal locations of PVAs and WTGs in a radial distribution system. The active energy loss have been minimized considering the constraints on bus voltages, line loadings, number of DGs to be placed and dispatched wind power. The allocation vectors for DGs have been represented in two dimensions so as to calculate power injections and DG outputs in a simple manner.

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"Turning off WTG" and "Clipping WTG output" control/operation strategies have been simulated to keep the dispatched wind power within a specified percentage of system loads. Using probabilistic techniques, the uncertainties associated with load and renewable resources have been modeled and the expected values of various variables of interest have been calculated. To reduce the search space and thereby to minimize the computational burden, a sensitivity analysis technique has been employed to select the candidate buses for DG allocation. To solve the developed formulation, being a combinatorial optimization problem with non-monotonic solution surfaces, an EP based algorithm has been developed as classical optimization techniques are not well suited to solve this type of problems. To generate the population, an index based scheme has also been developed ensuring the feasibility of each individual and thus considerably reducing the computational time. The proposed technique has been applied to a 69-bus distribution test system. Optimal DG placement results in reduced energy losses and improved voltage profile in the system. There are variations in the optimal locations of DGs with the number of DG units, the value of WPDLR and applied control strategy for wind turbines. The system performance improves with increase in the value of wind power dispatch to load ratio. For a distribution system with wind turbines, "Clipping WTG output" control mode enhances system performance in a better way in comparison to "Turning off WTG" control mode. Allocation of several DG units of smaller sizes in the system is more beneficial for improvement in the system performance as compared to the allocation of few DG units of large size. Though only wind and solar energy generation technologies have been used for placement in this paper, the developed approach can also be applied to place other renewable energy technologies such as run-of-river hydro in the distribution system by selecting suitable probability distribution functions for respective renewable resources.

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